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INVESTIGATION OF WILCOX MODEL 585B VERY HIGH FREQUENCY OMNIDIRECTIONAL RADIO RANGE (VOR) SYSTEM (PART 3)

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FINAL REPORT

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16. Abstract

A three-part investigation of the Wilcox 585B Very High Frequency Omnidirectional Radio Range (VOR) System was conducted. In Part 1, the magnitude of the ground error was reduced by modification and suitable adjustment of antenna element lengths of the field detector. In Part 2, investigation developed an acceptable calibration procedure for system 30 hertz (Hz) modulation. Obtaining compatible 30 Hz modulation reading between aircraft (far-field) and "edge of counterpoise" (near-field) measurements was an additional requirement. In Part 3, tests resolved any discrepancies in the tuning adjustments prescribed by the manufacturer's equipment manuals.

This report, which is the last in a series of three, contains an outline of the tests and procedures for setting the lengths of the adjustable field detector elements, a recommended procedure for obtaining compatible near-field and airborne 30 Hz modulation readings, and recommended changes to the manufacturer antenna tuning procedures in order that the system meet required operational tolerances.

This effort is in response to FAA Form 9550-1, AAF-410-078-003.

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METRIC CONVERSION FACTORS

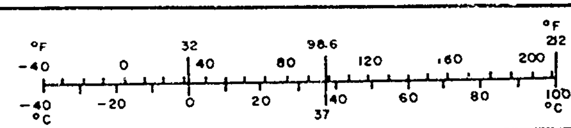
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The purpose of this project was to investigate a Wilcox model 585B Very High Frequency Omnidirectional Radio Range (VOR) System to reduce the magnitude of the ground error, develop an acceptable calibration procedure for system 30 hertz (Hz) modulation, and to correct the nonconformity of the initial adjustments wherein specification limits were exceeded. Investigation considerations included developing adjustment procedures and minor equipment modifications.

BACKGROUND.

There are several VOR stations in the National Airspace System operating with waivers because the initial adjustments did not conform to the criteria in the Federal Aviation Administration (FAA) Handbook 6790.4A, "Maintenance of VHF Omnirange Equipment." A request, via FAA Form 9550-1, AAF-410-078-003 was initiated for the Technical Center to investigate the manufacturer's tuning procedures and system tolerances, to investigate ground check error components, and to develop calibration procedures for the field detector employed in making the space modulation adjustment. Several system elements that can contribute to the error in the ground check include the field detector, antenna, goniometer, transmitting equipment, and counterpoise. The effort associated with the reduction of ground check error was previously reported in FAA Technical Center letter report NA-80-27-LR, "Investigation of Wilcox 585B VOR System (Part 1)" (see appendix B). The calibration procedure was reported in the interim report number FAA-RD-80-124, "Investigation of Wilcox Model 585B VOR System (Part 2)," dated April 1981, by Wayne Bell and James Dong. Pertinent information from both of these reports is included herein.

DESCRIPTION OF TEST FACILITY.

The Wilcox model 585B VOR station was installed at the center of a 400-foot diameter asphalt pad adjacent to the main runway at the FAA Technical Center. Figure 1 shows the circular metal shelter used to house the system with the modified field detector in a bracket position.

The equipment cabinets shown in figure 2 contain a complete dual transmitter/dual monitor system. Included in cabinet No. 1 are a monitor/VOR test generator, a local control panel, a radiofrequency (RF) distribution unit, a goniometer, a transmitter, modulator/power supply/keyer, a terminal board panel, and a blower. Since the cabinets are identical, the control unit and test generator can be installed in either cabinet.

TEST PROCEDURES AND RESULTS

GENERAL.

Investigation of the Wilcox 585B VOR System was accomplished in three parts. In part one, the magnitude of the ground error was reduced by modification and suitable adjustment of antenna element lengths of the field detector. The second part of the investigation developed an acceptable calibration procedure for system 30 Hz modulation. Obtaining compatible 30 Hz modulation readings between aircraft (far-field) and "edge of counterpoise" (near-field) measurements was an additional requirement. In part three, tests resolved any discrepancies in the tuning adjustments prescribed by the manufacturer's equipment manuals.

A Convair 580 aircraft, N-49, and a Grumman Gulfstream, N-47, were employed to obtain flight test recordings of bearing information using a Bendix FA-4165.3A receiver. The amplified

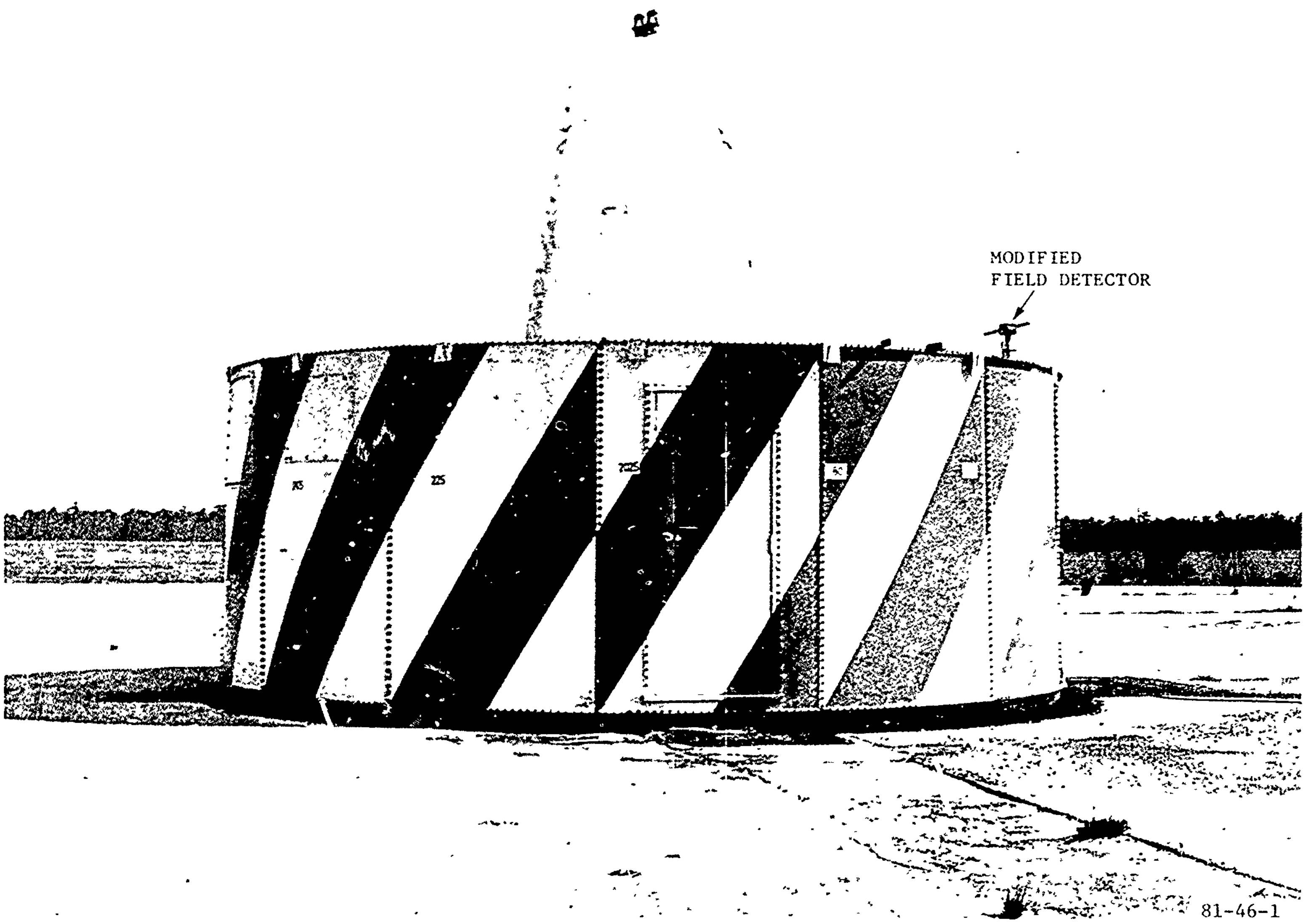

FIGURE 1. 'ILCOX MODEL 585B SHELTER

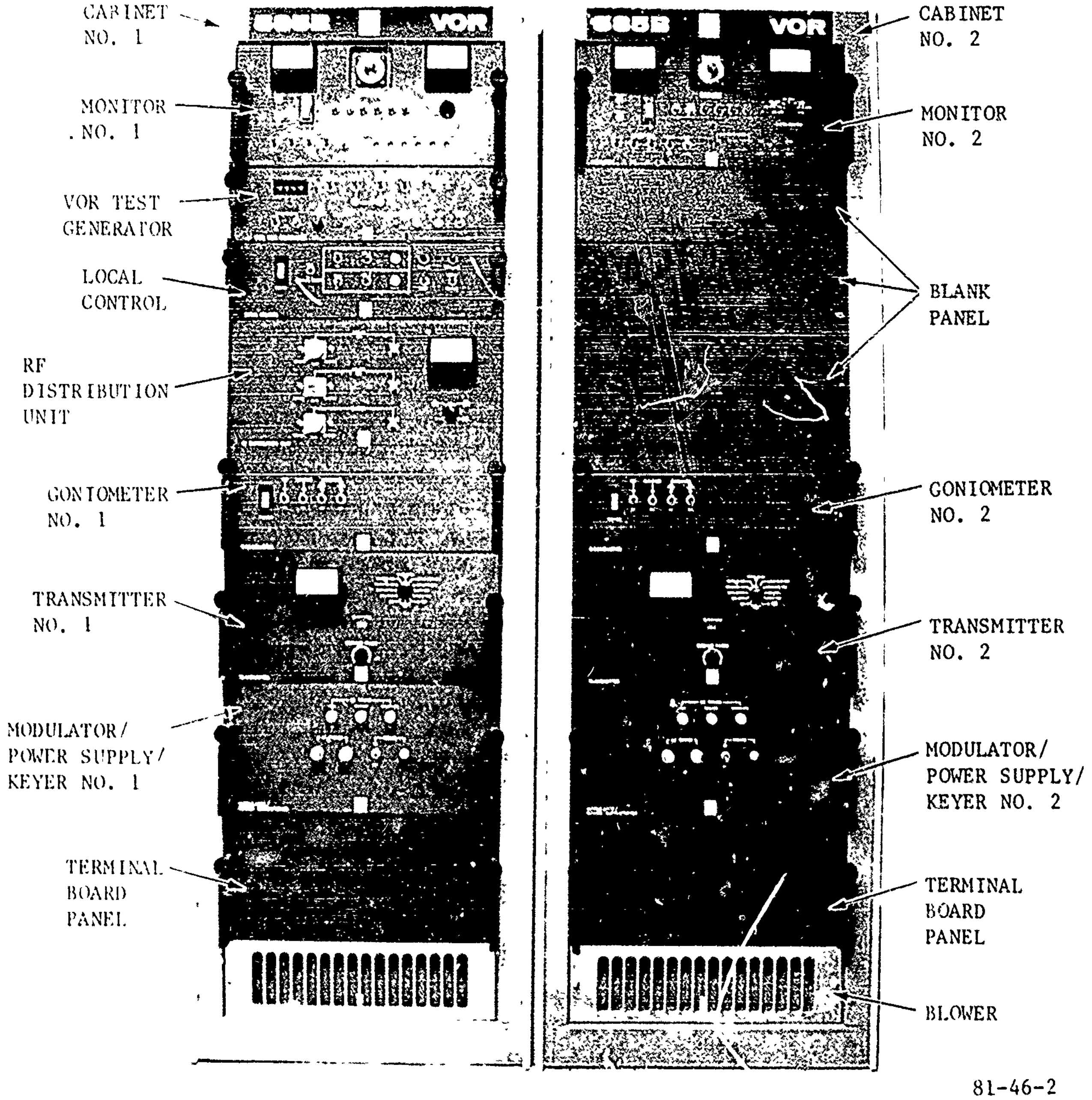

FIGURE 2. WILCOX MODEL 585B VOR CABINETS

course deviation indicator (CDI) voltage of the receiver was recorded with a dual-channel Texas Instruments rectilinear recorder.

Ten-nautical-mile (nmi) orbits at 1,500 feet above mean sea level (m.s.l.) and 25-nmi orbits at 2,500 feet above m.s.l. were flown to obtain a sampling of the course radiated by the VOR system operating at 109.0, 112.25, and 116.7 megahertz (MHz). Course sensitivity (space modulation), polarization effect, roughness, and scalloping were recorded on the 90° and 135° radials at an altitude of 1,500 feet above m.s.l. and a distance of 20 nmi.

Reference track for all orbits was provided by the Extended Area Instrumentation Radar (EAIR). Distance guidance and 10° azimuth marks from the EAIR were used by the aircraft for orbital flights; 2-nmi distance marks and azimuth guidance were provided by EAIR to the aircraft on all radial flights.

FIELD DETECTOR INVESTIGATION.

Tests were conducted to determine the magnitude of the ground check error component caused by the field detector/element. The design factors considered were raising the inductor-capacitor (L-C) tank circuit above RF ground to improve detector balance and optimizing the length of the detector antenna elements to reduce reradiation.

The monitor/field detector is used when making ground checks to determine/establish bearing accuracy of the VOR system. The monitor consists of four channels, each of which evaluates a different parameter of the VOR station output signal. The four channels are: (1) identification (keyed 1020 Hz), (2) subcarrier level (9960 Hz), (3) variable level (30 Hz), and (4) phase (compares the phase of the 30-Hz variable to that of the 30-Hz reference). The field detector supplies a demodulated signal to a monitor where comparisons are made to preset signal levels. An alarm is initiated when the comparison of the detected signals are not within the established limits of the preset signal level.

The standard and modified field detectors investigated are shown in figure 3. Figure 4 is a schematic of the modified detectors. In each detector tested, care was taken to keep coil L1 center-tap balanced with the coil being compressed or expanded to allow capacitors C2A and C2B to be adjusted for maximum signal. Detector accuracy (balance) was measured by the difference between the monitor resolver dial reading with the field detector mounted normally and when reversed 180°. A difference of ±0.2° is the maximum allowable as defined in the Wilcox instruction manual.

The standard Wilcox detector had the center tap of L1 grounded while the modified detector had an Ohmite Z-144, 1.8 microhenry RF choke connected between L1 center tap and ground. The 1.8 microhenry RF choke was selected because it has been used successfully in other types of VOR field detectors. The antenna elements for the standard detector were 12 7/8 inches long, while those of the modified detector were adjustable in length. The design of the adjustable antenna element for the modified field detector is shown in figure 5.

The test setup shown in figure 6 was configured to determine the proper element length for the field detector when mounted 10.5 feet from the VOR antenna tuned to operate at 116.7 MHz. The amplified detected signal from the yagi antenna on the 135° radial was fed to monitor No. 1 and the Hewlett-Packard model 7402 recorder. The yagi signals were used to balance monitor No. 2 with the field detector disconnected and removed from the counterpoise. Monitor No. 2 connected to the field detector with adjustable elements was used to

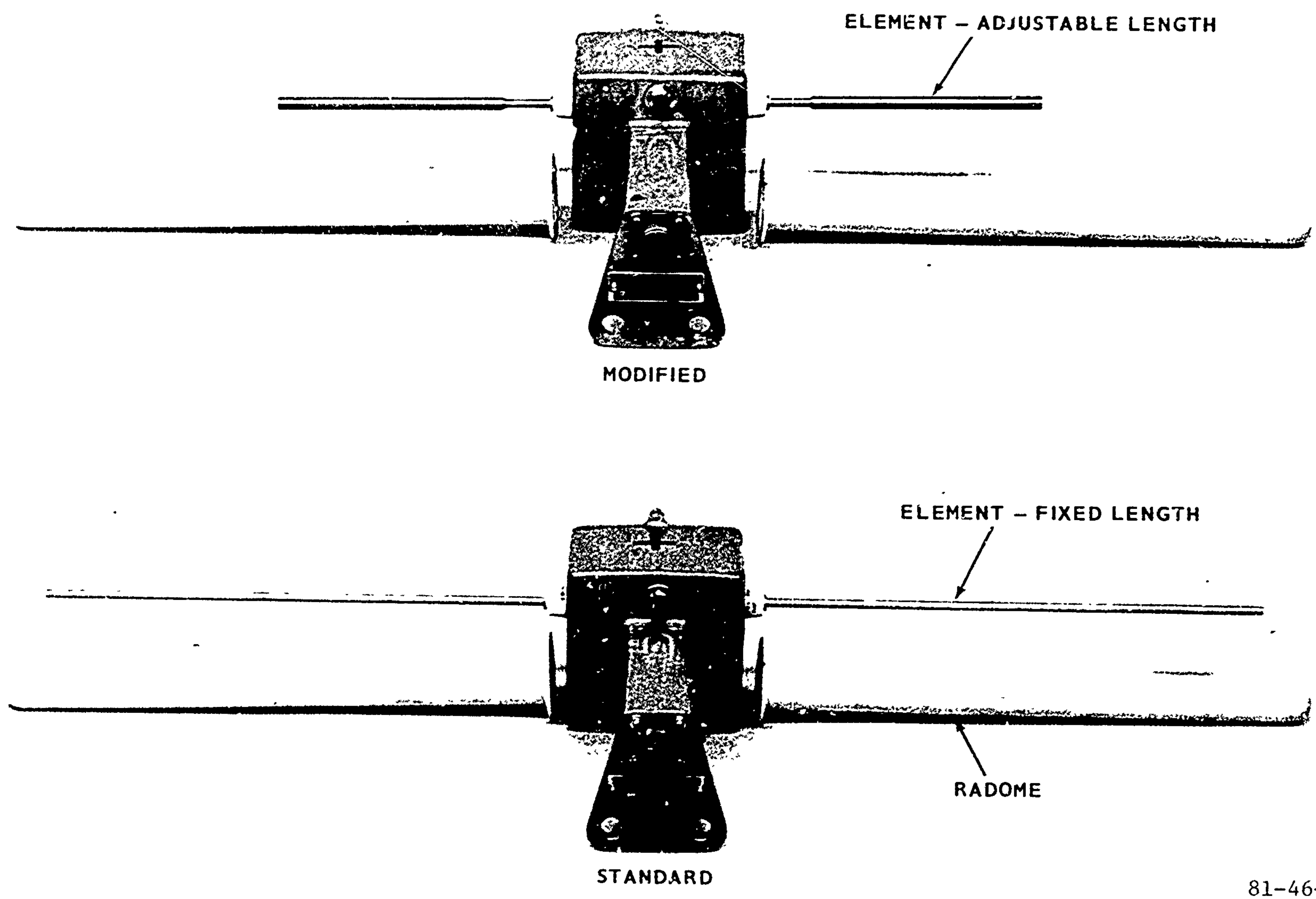

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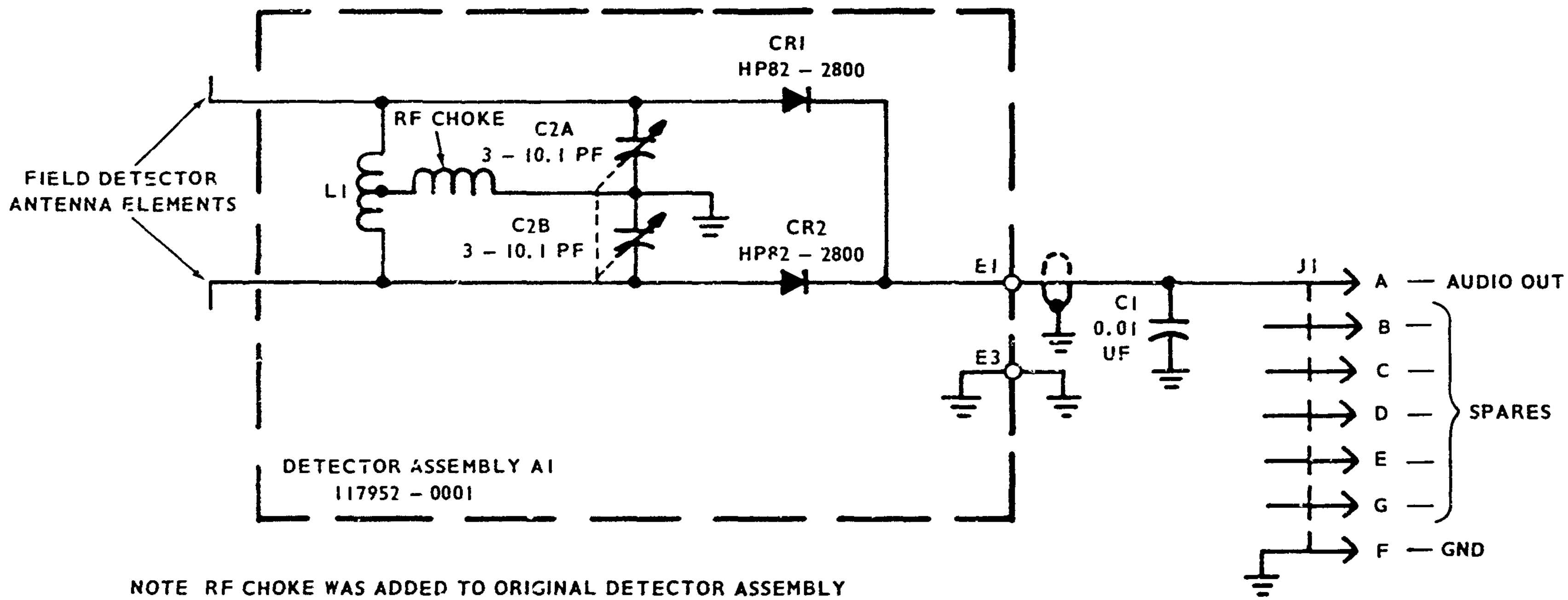
FIGURE 3. STANDARD AND MODIFIED WILCOX FIELD DETECTOR



NOTE RF CHOKE WAS ADDED TO ORIGINAL DETECTOR ASSEMBLY

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FIGURE 4. MODIFIED WILCOX FIELD DETECTOR SCHEMATIC DIAGRAM

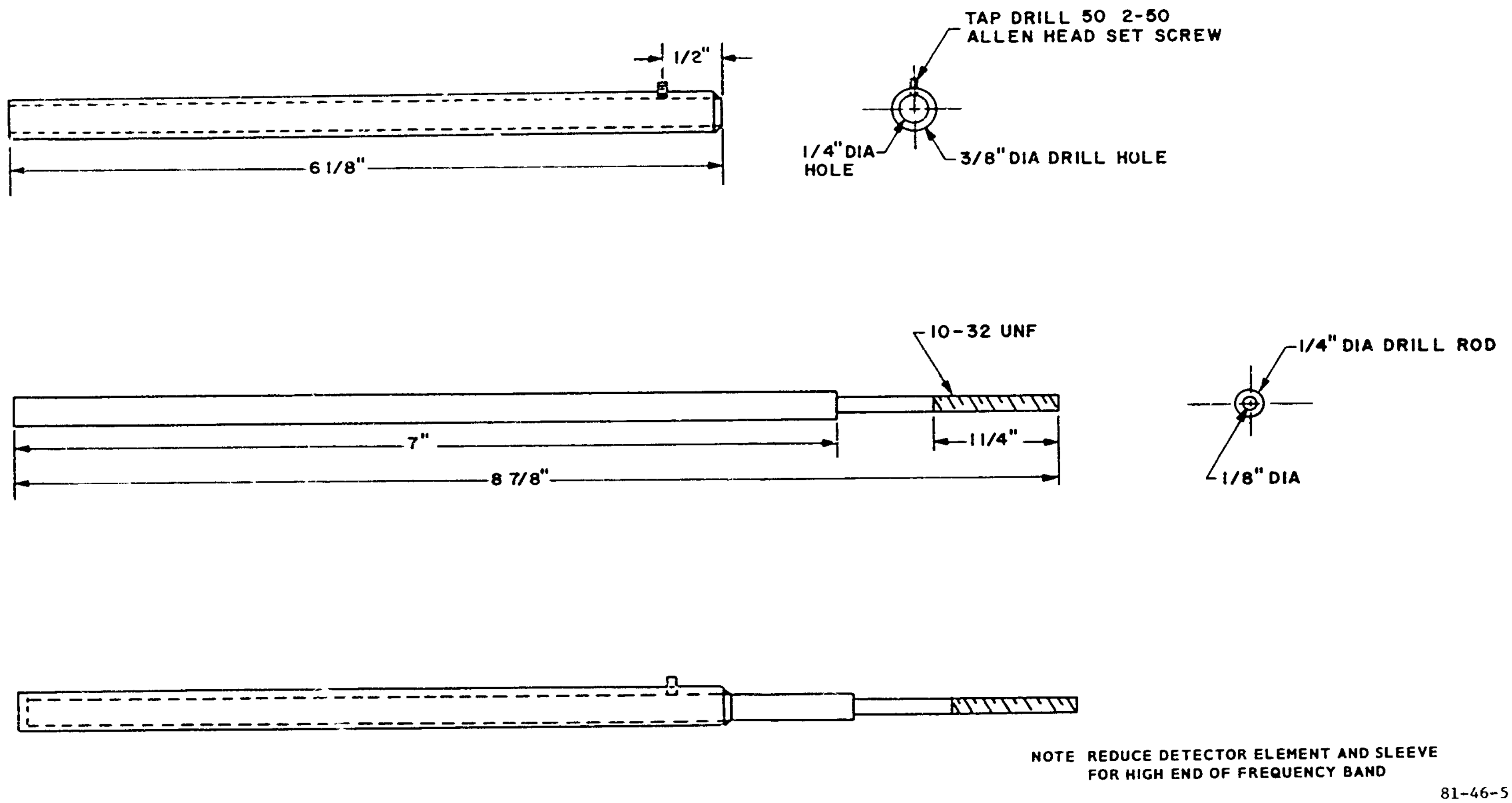

FIGURE 5. FIELD DETECTOR ANTENNA ELEMENT WITH ADJUSTABLE SLEEVE

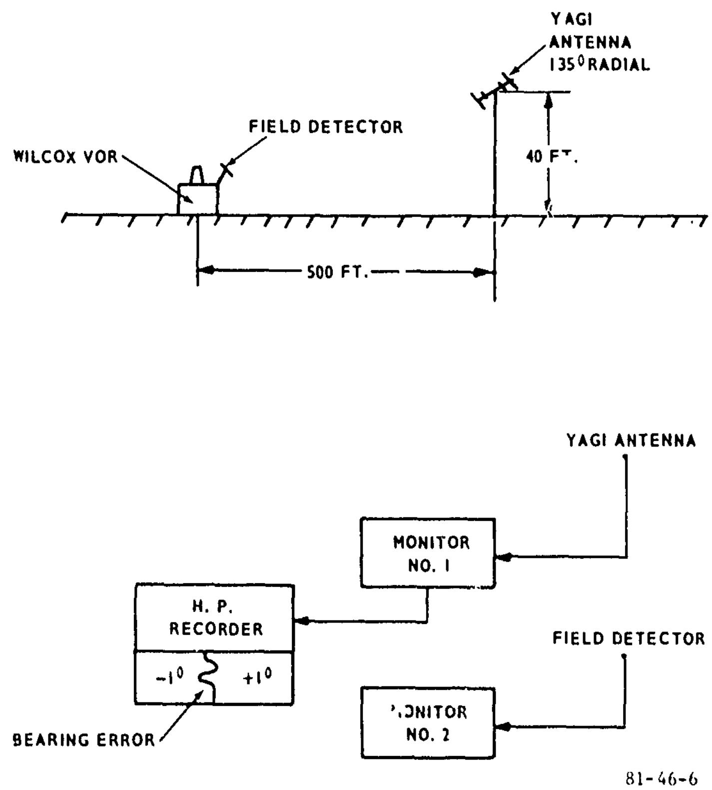

FIGURE 6. TEST SETUP TO DETERMINE PROPER FIELD DETECTOR ELEMENT LENGTH

assure that sufficient signal was available when minimum interference was observed on monitor No. 1. When the detector elements were extended greater than 12 7/8 inches, monitor No. 2 operation was unstable due to the increase in signal level. Therefore, no data were collected for element lengths greater than 12 7/8 inches. In addition, data collection ceased when monitor No. 2 indicated a minimum operationally acceptable level of 150 microamps of 30 Hz variable signal level on monitor meter M2 required for satisfactory operation of all monitoring functions.

For each selected element length, the field detector with adjustable elements was mounted successively at 22.5° intervals around the counterpoise edge, while the recorder processed the yagi detected course distortion (bearing error) caused by parasitic reradiation from the detector antenna elements. Once the minimum element length was established, a standard ground check error curve was taken from the edge of the counterpoise to compare the indicated course using the standard detector with that of the modified detector. Results of these tests accomplished at 116.7 MHz are shown in figures 7 and 8. Figure 7 shows the yagi detected bearing error caused by parasitic reradiation from the field detector mounted on the counterpoise edge. The bearing error was measured by the yagi antenna located at 135° azimuth, 500 feet from the facility, and 40 feet in height. Minimum element length was determined to be 3 7/8 inches for this frequency. The detector antenna element length could have been decreased further, as indicated in figure 7, resulting in an additional reduction of bearing error. However, the minimum operational acceptable

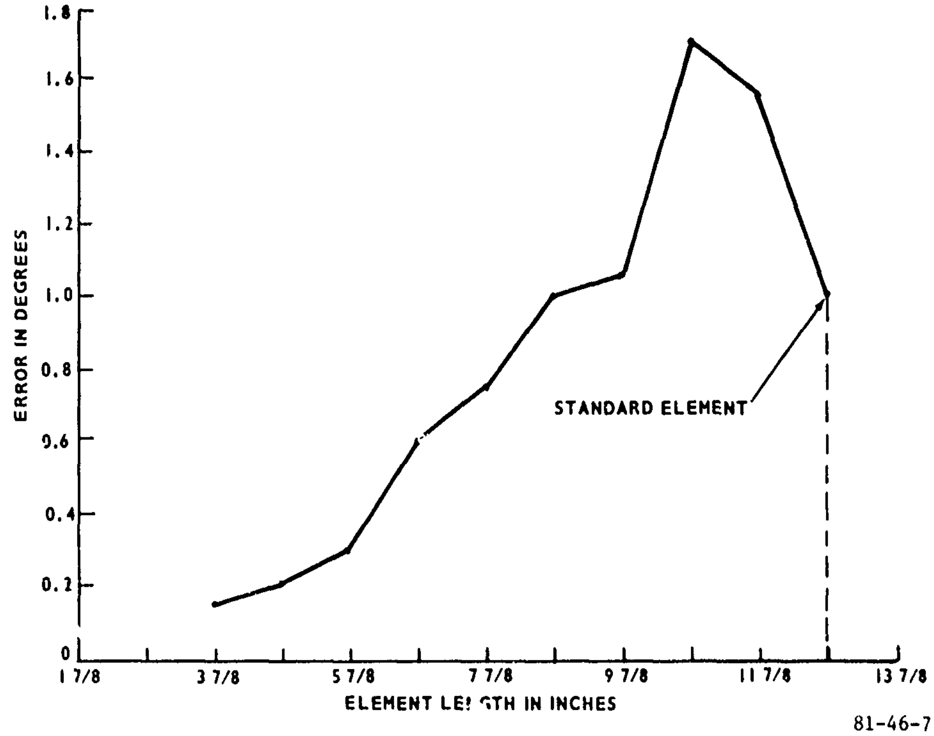

FIGURE 7. MAXIMUM ABSOLUTE BEARING ERROR VERSUS FIELD DETECTOR ELEMENT LENGTH — FIELD DETECTOR MOUNTED AT 22.5° INTERVALS AROUND THE COUNTERPOISE EDGE, FREQUENCY 116.7 MHz

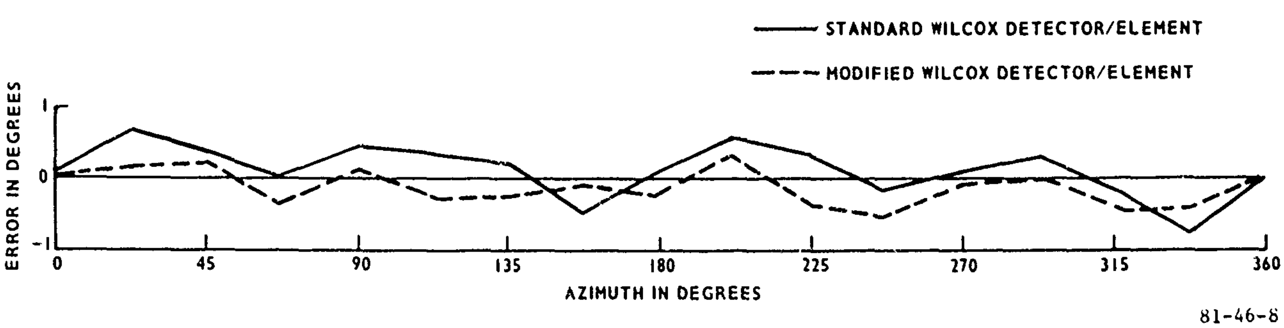

FIGURE 8. GROUND CHECK ERROR CURVE, FREQUENCY 116.7 MHz, MODIFIED VERSUS STANDARD DETECTOR/ELEMENT

monitor No. 2 signal level was reached at the 3 7/8 inch element length precluding further reduction. Figure 8 shows the ground check error curve using a standard and modified field detector. The peak-to-peak error measured with the unmodified field detector was 1.4, whereas, it was 1.1 with the modified field detector.

Table 1 tabulates the improvement in detector balance obtained with modifications and adjustments compared to the standard detector. Three standard Wilcox field detectors were used in the investigation.

Radial flights were accomplished at 1,500 feet m.s.l. with guidance provided by EAIR. The results of the radial flights shown in figure 9 indicate the reduction of scalloping/roughness using the modified detector with proper length elements.

Ground measurements were accomplished at 109.0 and 112.25 MHz to provide information on the optimum element length for various frequencies. The bearing errors for 109.0 MHz are shown in figure 10. Figure 11 contains the results of 112.25 MHz. It was determined that the optimum element length was 6 7/8 inches for a station frequency of 109.0 MHz; the optimum element length was 5 inches for 112.25 MHz.

With the optimum element length established at 109.0 and 116.7 MHz, the optimum length was predicted for 112.25 MHz, assuming that the optimum length varied linearly with frequency, as shown by the dotted line in figure 12. However, the measured value at 112.25 MHz for the optimum element length did not agree with the predicted value. The difference between the measured and predicted value was caused by the optimum element length established for 116.7 MHz. The optimum length at this frequency was determined by reaching minimum signal level required for proper monitoring, not minimum bearing

TABLE 1. MEASURED DETECTOR BALANCE ERROR

Field Detector Sample	Condition	Detector Balance Error (degrees)
No. 1	Standard Detector/Element	±0.6
	RF Choke Added	±0.15
	Modified Detector/Element	±0.1
No. 2	Standard Detector/Element	±0.4
	RF Choke Added	±0.15
	Modified Detector/Element	±0.15
No. 3	Standard Detector/Element	±0.2
	RF Choke Added	±0.15
	Modified Detector/Element	±0.15

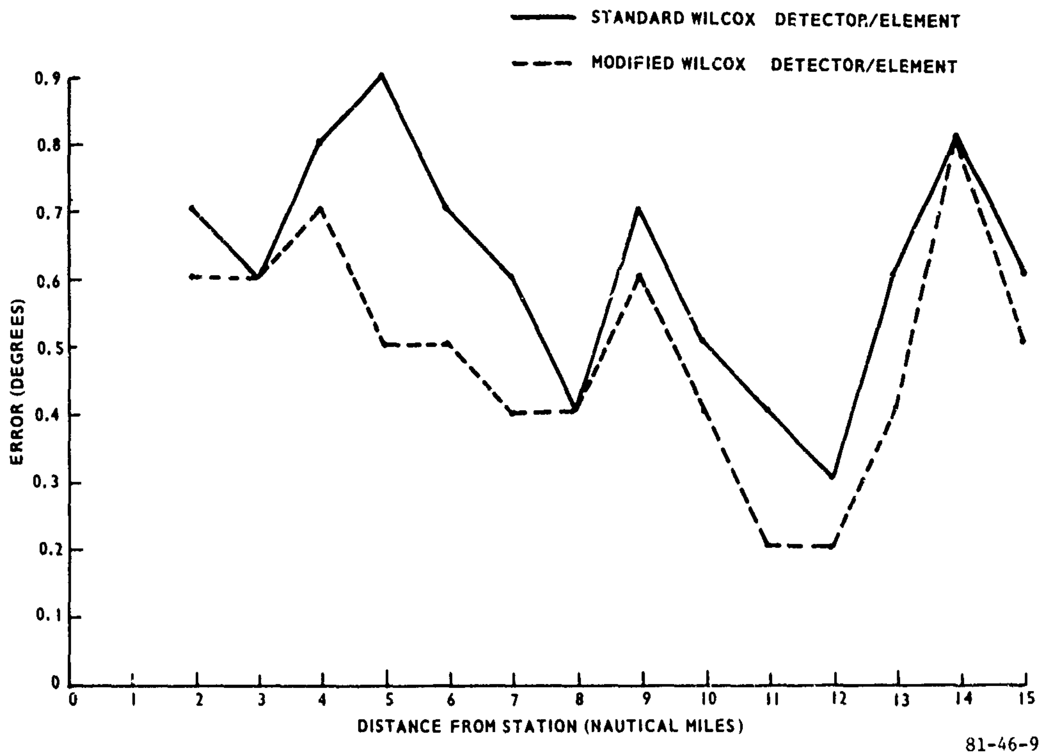

FIGURE 9. MAXIMUM SCALLOPING/ROUGHNESS ERROR, 135° RADIAL INBOUND, MODIFIED VERSUS STANDARD DETECTOR/ELEMENT

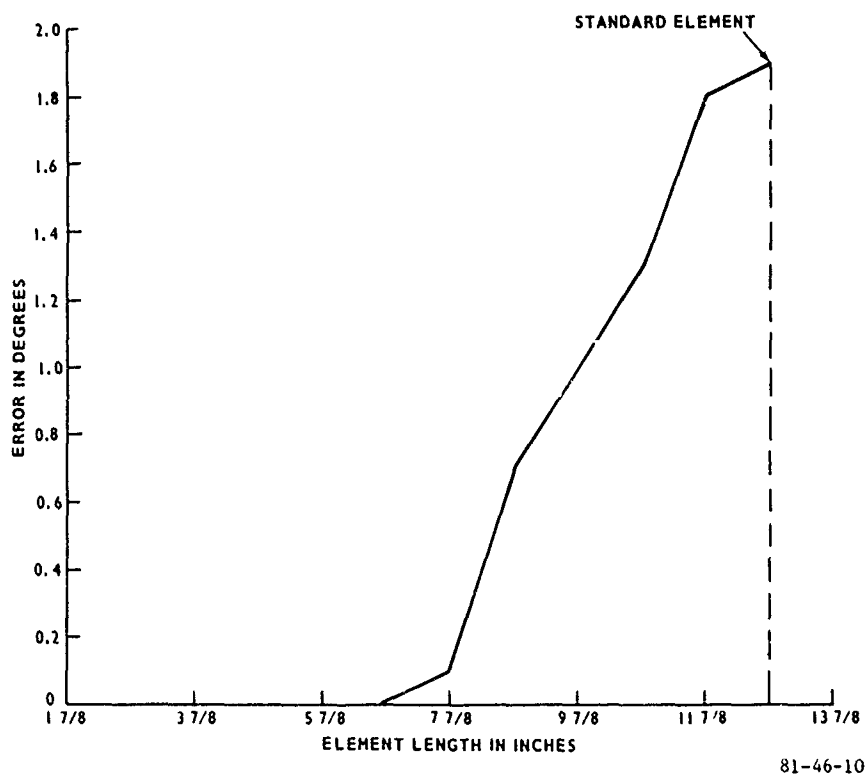

FIGURE 10. MAXIMUM ABSOLUTE BEARING ERROR VERSUS FIELD DETECTOR ELEMENT LENGTH — FIELD DETECTOR MOUNTED AT 22.5° INTERVALS AROUND THE COUNTERPOISE EDGE, FREQUENCY 109.0 MHz

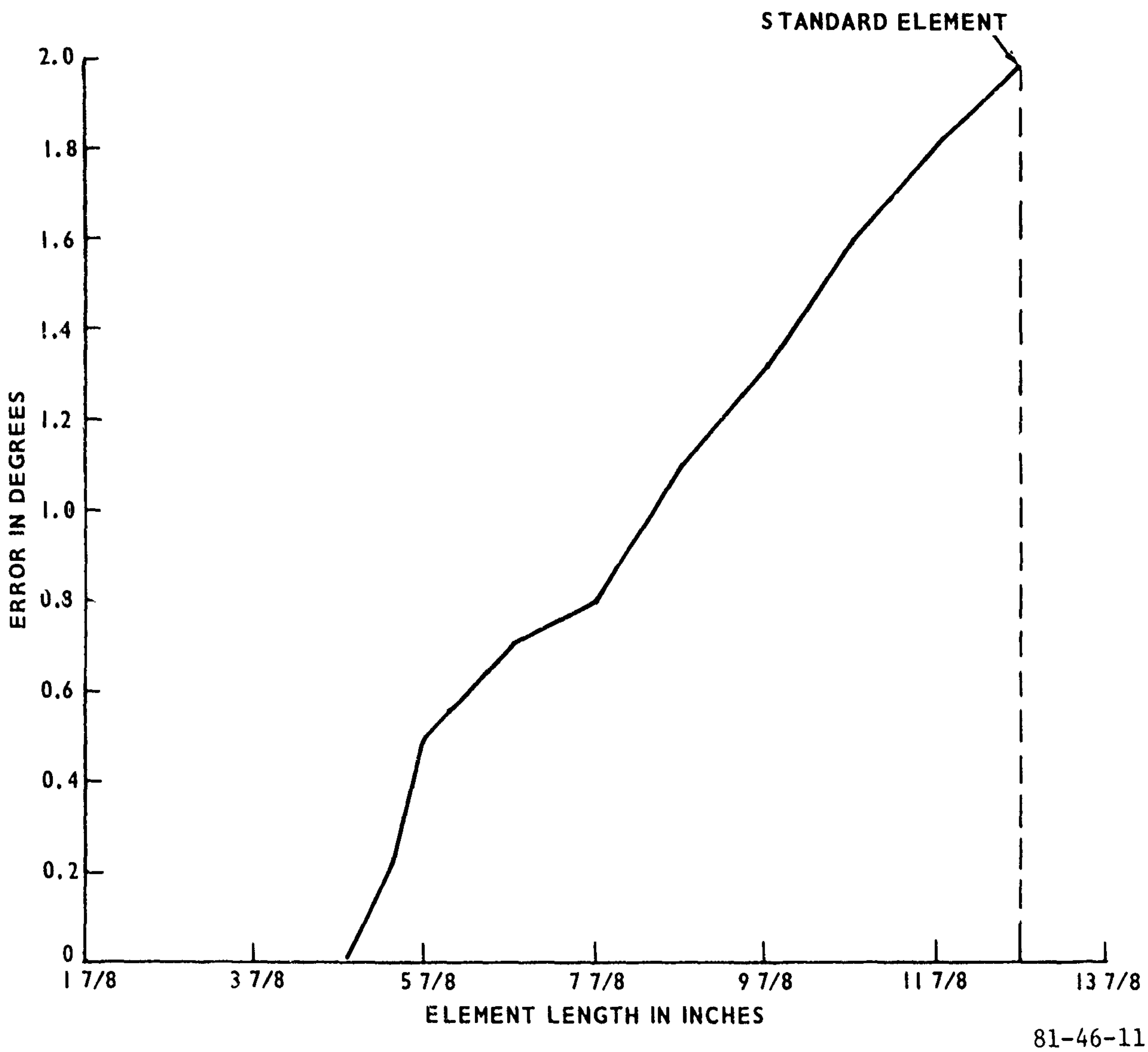

FIGURE 11. MAXIMUM ABSOLUTE BEARING ERROR VERSUS FIELD DETECTOR ELEMENT LENGTH — FIELD DETECTOR MOUNTED AT 22.5° INTERVALS AROUND THE COUNTERPOISE EDGE, FREQUENCY 112.25 MHz

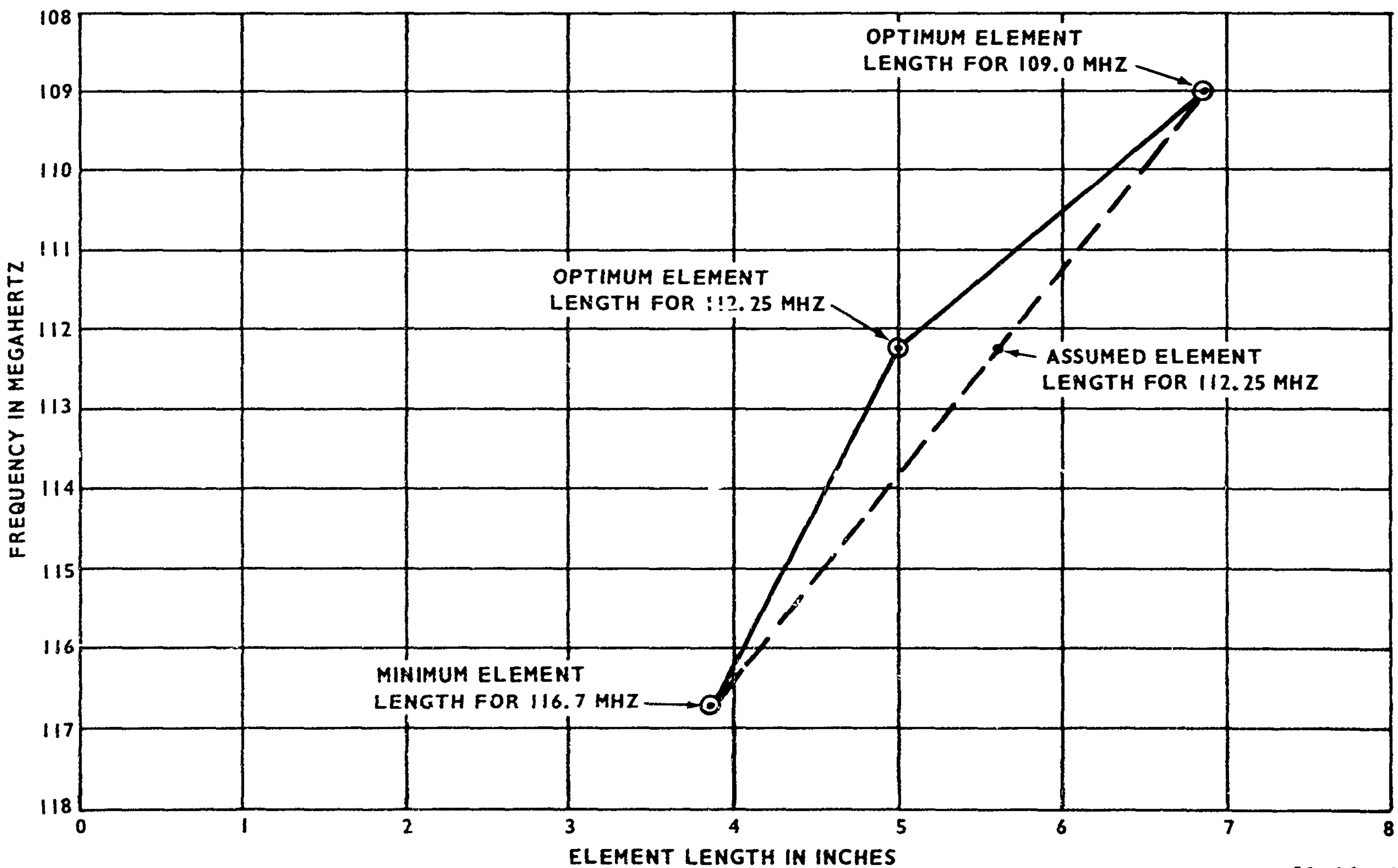

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FIGURE 12. WILCOX DETECTOR ELEMENT ADJUSTMENTS

error. Taking minimum monitor signal requirements into consideration, the proper element lengths for other frequencies can be determined by the solid line of figure 12.

Ground measurements were accomplished at Calverton, Long Island, Very High Frequency Omnidirectional Radio Range and Tactical Air Navigational (VORTAC) facility (117.2 MHz) and Salisbury, Maryland, VORTAC (114.5 MHz) to provide information on optimum detector element length at field sites with 32- and 52-foot diameter counterpoise, respectively. Results of the bearing error for the 32-foot counterpoise are shown in figure 13; results for the 52-foot counterpoise are shown in figure 14. Results indicate that the bearings error can be reduced by modifying and reducing the field detector element length. A simple procedure for adjusting the element length is to adjust the field detector antenna element for a monitor 30-Hz amplitude modulation (AM) signal level reading of 150 on monitor meter M2.

MODULATION 30-Hz INVESTIGATION.

The Wilcox 585B VOR installation manual does not include a calibration procedure for the field detector diodes. The specified 20° course sensitivity of the VOR is dependent upon the space modulation being 30 percent. Space modulation (variable signal level) is adjusted and monitored by the field detector. A method of calibrating the field detector diodes to obtain a space modulation chart was required. The tests were accomplished with the Wilcox test site operating at a frequency of 109.0 MHz. Instrumentation employed in the testing include a Fluke model 8600K digital multimeter, Hewlett-Packard model 7402A recorder, and a Hewlett-Packard spectrum analyzer comprised of a model 141T display unit, a model 8553B RF unit, and a model 8552B intermediate freqeuncy (IF) unit. Documents used as guidance in formulating the VOR field detector calibration procedure include "Maintenance of VHF Omnirange Equipment" and "VHF Omnidirectional Radio Range (VOR) Electromagnetic Spectrum Measurements" (references 1 and 2). These procedures calibrate the nonlinear field detector diode and assure that ground measurements made with the calibrated field detector to obtain the space modulation chart did not introduce adjustment errors to the airborne measurements. The Wilcox model 585B VOR System has a solid-state goniometer instead of a mechanically rotatable unit contained in earlier VOR models. Consequently, the field detector was moved successively to the several counterpoise ground-check bracket locations to obtain intermediate values between the minimum and maximum. The measured values of field intensity correspond to radial position measurements made by keeping the field detector fixed and rotating the mechanical goniometer. The basic procedures in the FAA Handbook AF-6780.4A, "Maintenance of VHF Omnirange Equipment," were applied.

The recommended procedure for obtaining the space modulation chart for use with solid-state VOR equipment is presented in appendix A.

NEAR- AND FAR-FIELD EQUALITY MEASUREMENT.

Tests were conducted to determine if the calibration procedure for a space modulation chart detailed in appendix A would permit comparable percent modulation readings (30-Hz AM) between aircraft and edge of counterpoise indicators.

With the modified field detector at the 135° bracket position and using the space modulation chart, the modulation was adjusted to 30 percent (using the standard oscilloscope technique employed at VOR field sites for measuring the minimum and maximum 30 Hz AM). The spectrum analyzer was connected to a dipole antenna at the 135° bracket position (edge of counterpoise) and recordings made. Spectrums were

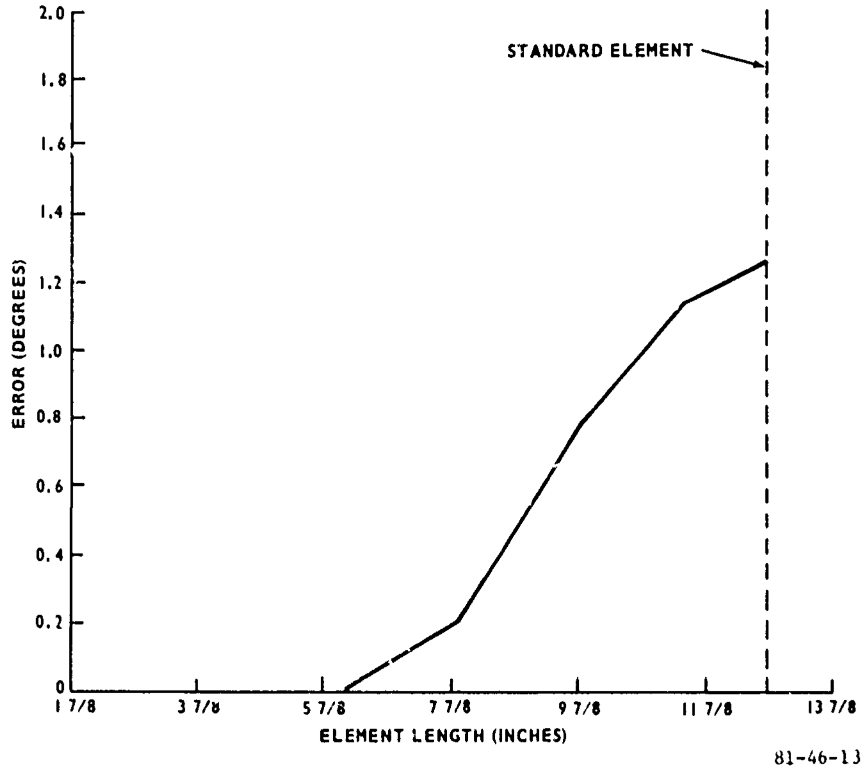


FIGURE 13. MAXIMUM ABSOLUTE BEARING ERROR VERSUS FIELD DETECTOR ELEMENT LENGTH — FIELD DETECTOR MOUNTED AT 22.5° INTERVALS AROUND THE COUNTERPOISE EDGE, 32-FOOT DIAMETER COUNTERPOISE, CALVERTON, NEW YORK

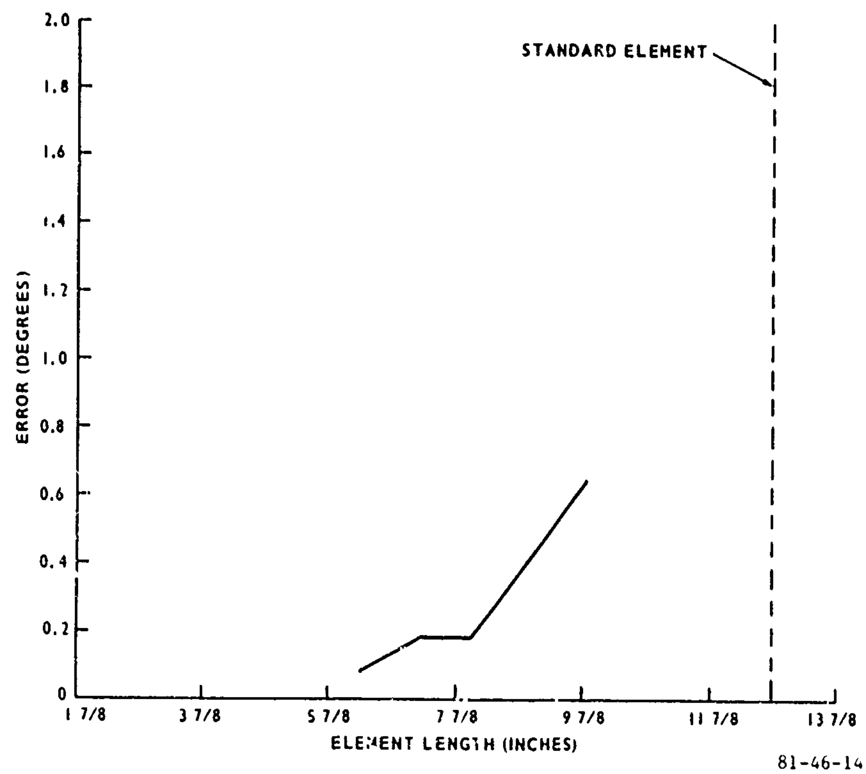


FIGURE 14. MAXIMUM ABSOLUTE BEARING ERROR VERSUS FIELD DETECTOR ELEMENT LENGTH — FIELD DETECTOR MOUNTED AT 22.5° INTERVALS AROUND THE COUNTERPOISE EDGE, 52-FOOT DIAMETER COUNTERPOISE, SALISBURY, MARYLAND

then recorded using the yagi antenna located 500 feet from the counterpoise. Finally, airborne spectrums were recorded with the spectrum analyzer aboard the N-47 (Grumman Gulfstream) aircraft flying inbound at an altitude of 1,500 feet m.s.l. at 140 knots at 90° and 135° radials. During these tests no changes were made to the VOR system adjustments.

Using the spectrum analyzer technique (reference 2), the modulation ratio is described as the ratio of sideband (E_S) to carrier (E_C), i.e., E_S/E_C. The values for this ratio were obtained from the recorded spectrums. Samples of the spectrums are shown in figure 15 with their average percent modulation for each test condition.

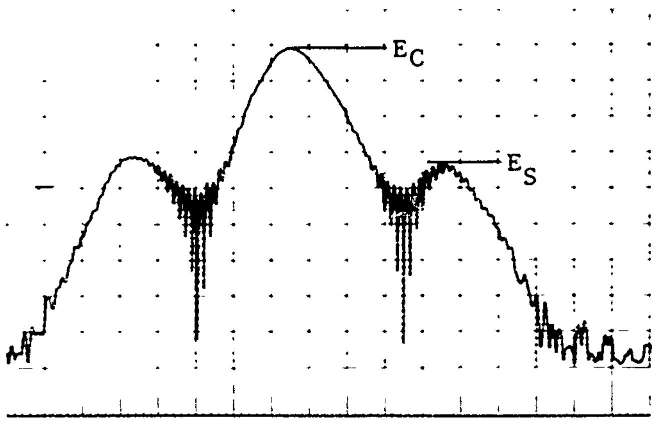
Average values were the same for the airborne spectrum data from the 90° and 135° radial flights inbound from 20- to 7-nmi range to the VOR site. The modulation value measured from the yagi antenna, located 500 feet from the counterpoise, was 0.3 of a percent greater than the airborne value, and 1.6 percentage points greater than the value measured at the edge of the counterpoise. If the 500-foot ground measurement is considered far-field and averaged with the airborne measurements, the difference between near- and far-field is a modulation percent difference of 1.45. Without any compensation for this difference, the procedure used to set the 30-percent optimum adjustment resulted in an airborne measurement well within the tolerance of 25 to 35 percent levels listed in reference 3.

ANTENNA ADJUSTMENTS AND TOLERANCES.

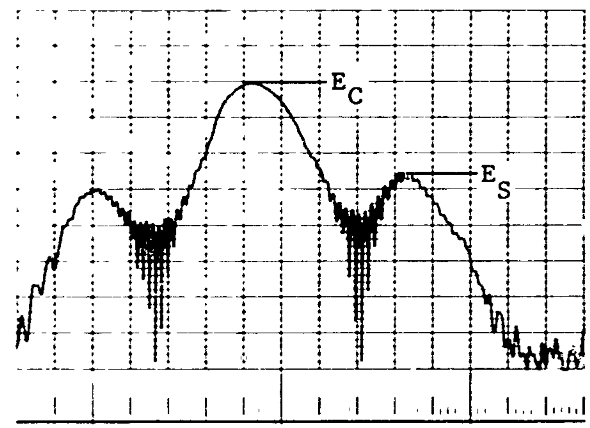
The latest model slotted-cylinder VOR antenna manufactured by Wilcox is claimed (by Wilcox) to meet all tolerances specified in chapter 4 of the FAA Handbook 6790.4A and Flight Inspection Manual OA P 8200.1. Ground and airborne measurements were made to determine if specified tolerances were achievable. The initial tolerances investigated were: ±0.75° ground check error, ±2.5° flight check error, and antenna transmission line voltage standing wave ratios (VSWR) of 1.02 or less for the carrier and sideband feed lines, with a goniometer input VSWR of 1.33 or less. Polarization effect was also measured to determine maximum deviation of course caused by vertical polarization (VP). The tolerance for VP is ±2° deviation.

Field Facilities use a built-in RF wattmeter in measuring VSWR of system components. A Hewlett-Packard model 8405 vector voltmeter and model 778D dual directional coupler were used as another technique (reference 4) to confirm VSWR measurement accuracy.

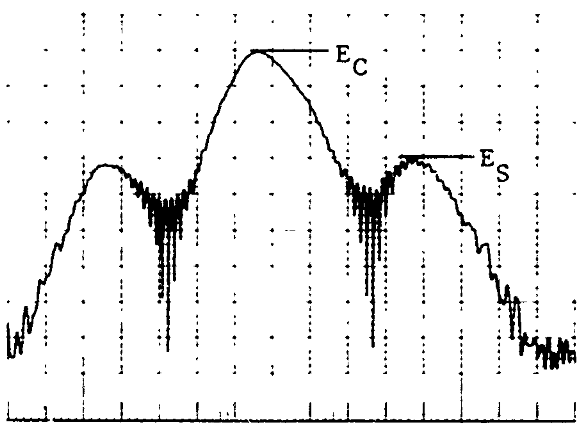
The slotted-cylinder antenna was tuned to 109.0, 112.25, and 116.7 MHz by adjusting its controls to prescribed settings obtained from the manufacturer's tuning chart. Additional fine tuning to reduce VSWR at each frequency was required. The antenna sideband feed lines and carrier feed line were checked separately using the built-in, thru-line wattmeter utilizing the carrier from the transmitter as the signal source. The manufacturer suggests adjusting the carrier power level to 20 watts for VSWR measurements. Even at this power level it was difficult to get accurate VSWR measurements. Therefore, these VSWR tests were conducted with the carrier power adjusted to 100 watts. The carrier feed line VSWR, when operating at 109.0 MHz, could not be reduced lower than 1.2. Carrier line adjustments (upper and lower plunger capacitors C2 and C4) would not reduce the reflected power. A "T" connector was installed in the carrier line at the antenna, and a stub was installed and adjusted to obtain minimum VSWR. Minimum VSWR was achieved when the stub was adjusted to 4 inches. Wilcox factory engineering confirmed this condition and they agreed that the stub was required to achieve a 1.02 VSWR when



EDGE OF COUNTERPOISE
AVERAGE E_S/E_C = 0.64 = 30 PERCENT



135° RADIAL 500 FT (YAGI)
AVERAGE E_S/E_C = 0.675 = 31.6 PERCENT



INBOUND 20 NMI (140 KNOT)
AVERAGE E_S/E_C = 0.667 = 31.3 PERCENT

HEWLETT PACKARD SPECTRUM ANALYZER SETTINGS

BANDWIDTH = 0.01 kHz

SCAN WIDTH = 0.02 kHz
SCAN TIME = 0.5 SEC/DIV

RECORDER CHART SPEED = 25 mm/SEC

81-46-15

FIGURE 15. SAMPLE SPECTRUM RECORDINGS

operating at the low end of the VOR frequency band.

After the antenna was tuned to each frequency, a ground check error curve was taken and goniometer adjustments were made to minimize station error. Prior to flight testing, the VSWR was recorded using both the RF wattmeter method and the vector voltmeter method.

A comparison of the VSWR readings using the RF wattmeter and vector voltmeter method is presented in table 2. The table shows that the VSWR commissioning tolerance of 1.02 was achieved only twice using the wattmeter, and never achieved using the vector voltmeter method. The VSWR measured with the vector voltmeter averaged 0.035 greater than the wattmeter readings. Also, the VSWR of 1.02 required for all three feedlines at each frequency was never achieved. The reflected power measured at the goniometer input was less than 300 milliwatts with 15 watts forward. This is within the specified VSWR tolerance of 1.33.

Results of the ground and airborne tests were within the established tolerances and are shown as follows. Figures 16 and 17 are presentations of data obtained while the station was tuned to 109.0 MHz. The maximum ground check error was ±0.55° and the maximum flight check error was ±1.7° for the 10- and 25-nmi orbit. Figures 18 and 19 show the maximum ground check error curve of ±0.65° and the maximum flight check error of ±1.5° for the 10-nmi orbit and ±1.46° for the 25-nmi orbit when operating at a station frequency of 112.25 MHz. Figures 20 and 21 show the maximum ground check and maximum flight check error while the station was operating at 116.7 MHz. The ground check error was ±0.6° and the flight check error was ±1.45° and ±1.5° for 10 and 25 nmi, respectively.

Two vertical polarization checks including 30° wing rock and heading effect were conducted. These tests were made approximately 20 nmi from the VOR at an altitude of 1,500 feet above m.s.l. A value of ±0.25° of VP error

TABLE 2. TABULATION OF INDICATED VSWR MEASUREMENTS

System Component	Frequency MHz 109.0	MHz 112.25	MHz 116.7	Commissioning VSWR Tolerance
Carrier Feedline VSWR				
RF Wattmeter	1.02	1.04	1.04	1.02
Vector Voltmeter	1.078	1.072	1.075	
No. 1 Sideband Feedline VSWR				
RF Wattmeter	1.01	1.03	1.03	1.02
Vector Voltmeter	1.067	1.052	1.074	
No. 2 Sideband Feedline VSWR				
RF Wattmeter	1.02	1.02	1.04	1.02
Vector Voltmeter	1.053	1.069	1.065	

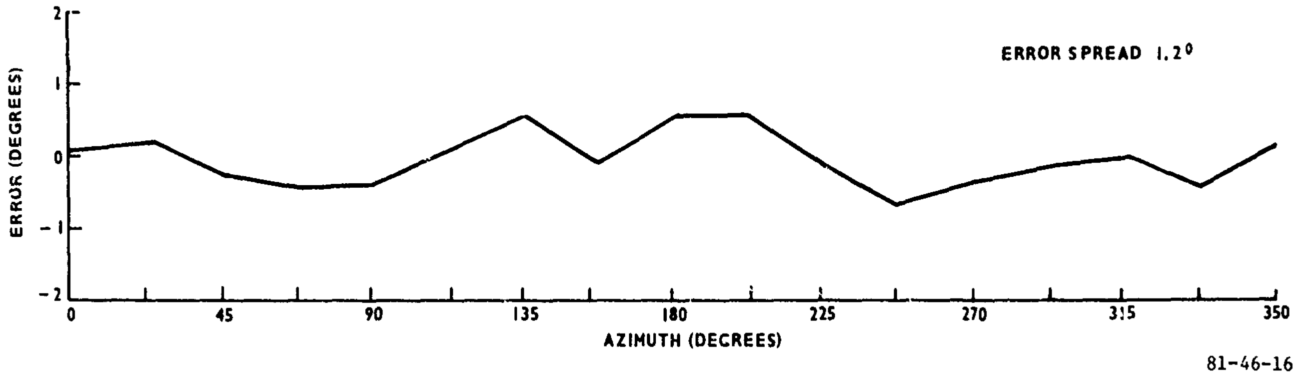


FIGURE 16. GROUND CHECK ERROR CURVE, STATION FREQUENCY 109.0 MHz

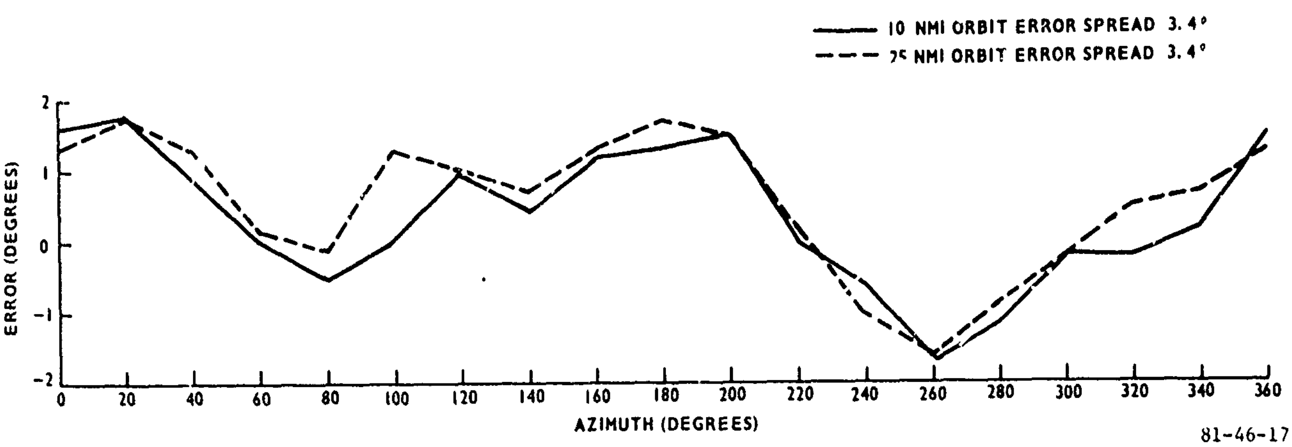


FIGURE 17. BEARING ERROR CURVE, BENDIX FA-4165.3A RECEIVER, 10 AND 25 NMI ORBIT, STATION FREQUENCY 109.0 MHz

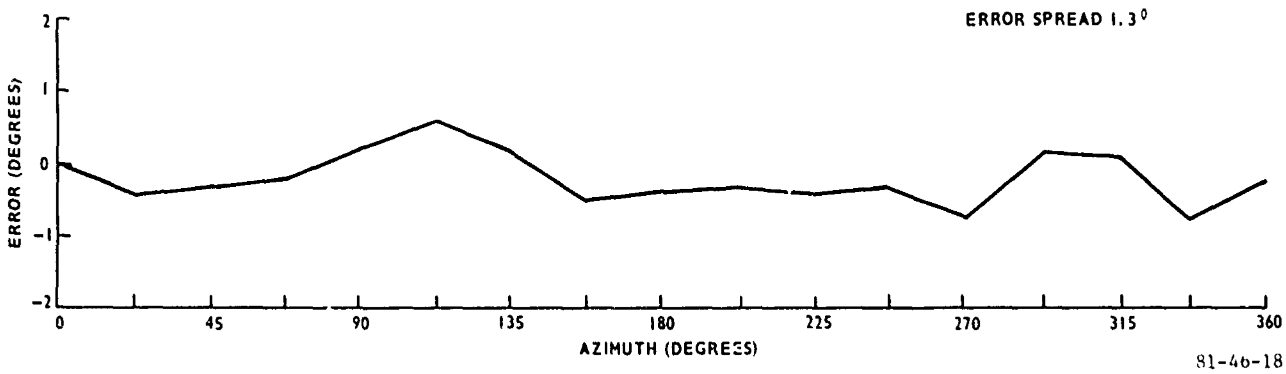


FIGURE 18. GROUND CHECK ERROR CURVE, STATION FREQUENCY 112.25 MHz

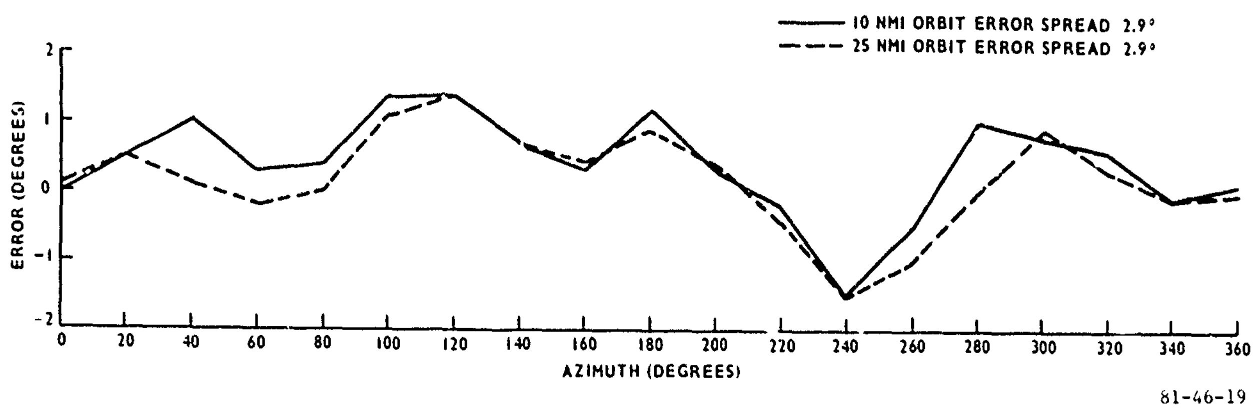


FIGURE 19. BEARING ERROR CURVE, BENDIX FA-4165.3A RECEIVER, 10 AND 25 NMI ORBIT, STATION FREQUENCY 112.25

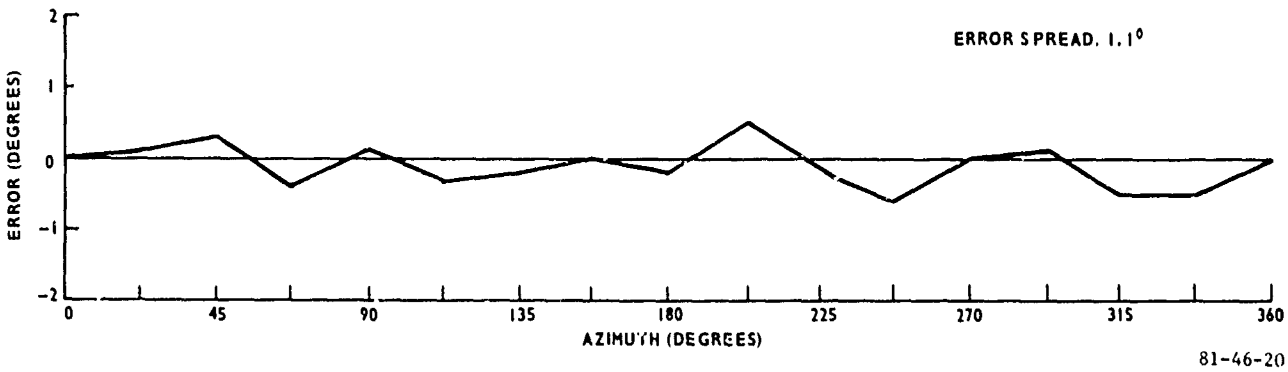


FIGURE 20. GROUND CHECK ERROR CURVE, STATION FREQUENCY 116.7 MHz

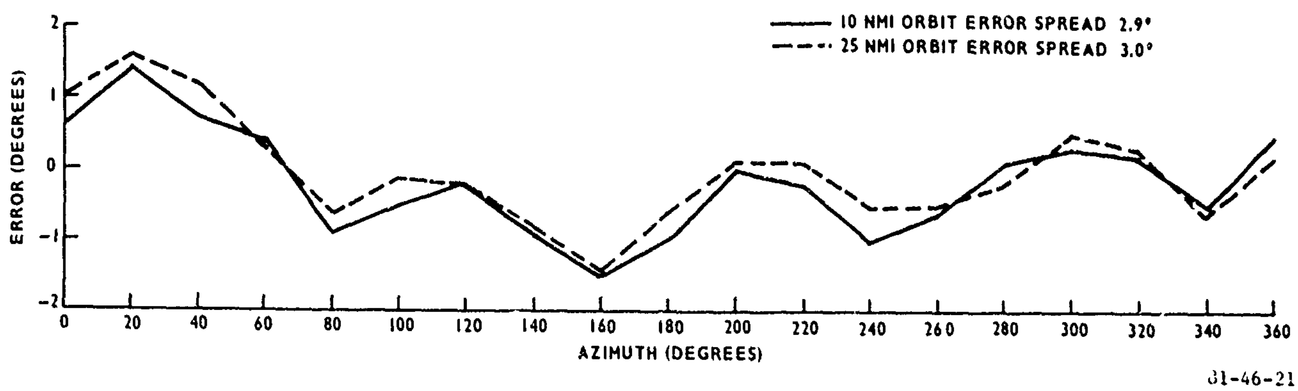


FIGURE 21. BEARING ERROR CURVE, BENDIX FA-4165.3A RECEIVER, 10 AND 25 NMI ORBIT, STATION FREQUENCY 116.7 MHz

was measured using the 30° wing rock method; a ±0.5° heading effect was recorded. Both of these results are within the established tolerance.

During a rainstorm, an unstable monitoring condition occurred resulting in a facility shutdown. The cause of this condition was moisture in the plug/connector (P_1/J_1) on the field defector. Making the plug/connector waterproof by using Devcon rubber (rubber in a semipaste form) and electrical tape eliminated the problem.

Component failures which occurred during 2 years of intermittent operation of the dual 585B VOR system are:

1. K-3 relay, component of modulator/power supply/keyer.

2. U-1 transistor, two each, modulator/power supply/keyer.

3. Power switch, component of monitor.

4. HP82-2800 diodes, two each, component of field detector.

CONCLUSIONS

Based on the test results, it can be concluded:

1. System improvement was obtained with the modification of adding a radio-frequency (RF) choke and keeping the inductor capacitor (L-C) circuit in the detector about RF ground.

2. Reduced course offset and bearing error were obtained by adjusting field detector elements to the proper length corresponding to frequency.

3. The ground check error was reduced by adding an RF choke and adjusting the field detector elements to proper length.

4. Minimal improvement was obtained in scalloping/roughness error.

5. A procedure employed for calibration of the diodes on the field detector in a solid-state Very High Frequency Omnidirectional Radio Range (VOR) System using field detector at ground check brackets can be used when there is no rotatable goniometer.

6. A spectrum analyzer technique used to measure percent modulation provided the accuracy to observe differences in near- and far-field measurements.

7. Using 100 watts of carrier power during the voltage standing wave ratios (VSWR) measurement resulted in more accurate VSWR measurements.

8. A "T" connector and stub must be added to the carrier feedline to achieve minimum VSWR.

9. The vector voltmeter VSWR measurements were greater than the RF wattmeter readings, but not significantly.

10. The initial VSWR tolerances listed in the "Maintenance of VHF Omnirange Equipment," FAA 6790.4A, cannot be achieved.

11. The initial ground check tolerance listed in FAA 6790.4A can be achieved.

12. Flight check tolerances listed in Handbook OA P 8200.1, "United States Standard Flight Inspection Manual," were achieved.

13. The vertical polarization error was negligible.

14. Field detector connector P_1/J_1 is subject to moisture contamination resulting in unstable facility monitoring.

RECOMMENDATIONS

Based on the investigation results, it is recommended that:

1. The modifications of a radio-frequency (RF) choke and the use of adjustable elements on the field detectors be employed at field sites with a Wilcox 585 Very High Frequency Omnidirectional Radio Range (VOR) System.

2. The calibration procedure included herein for obtaining a space modulation chart be used for solid-state VOR systems.

3. The Wilcox installation handbook be updated to include the addition of a "T" connector and stub in the carrier feed line.

4. The initial voltage standing wave ratio (VSWR) tolerances listed in FAA 6790.4A be changed to a maximum value of 1.08.

5. Procedures should be modified to reflect the use of 100 watts of carrier power during VSWR measurements.

6. Field detector connector (P_1/J_1) should be waterproofed to eliminate unstable facility monitoring caused by moisture contamination.

REFERENCES

1. Maintenance of VHF Omnirange Equipment, FAA New England Region supplement 6790.4A, AFI, March 16, 19'9.

2. Kanen, Garth M., VHF Omnidirectional Radio Range (VOR) Electromagnetic Spectrum Measurements, Technical Note, Project 213-060-78, October 1978.

3. United States Standard Flight Inspection Manual, FAA Handbook OA P 8200.1, Section 201.5, Chg. 27, May 1977.

4. Measurement of Complex Impedance, Hewlett Packard Application Note 73-3.

APPENDIX A

PROCEDURE SEQUENCE FOR SPACE MODULATION CHART

The transmitter carrier power, adjusted to 100 watts, is fed to the northwest (NW) and southeast (SE) antenna slots. This is sideband (SB) No. 1 (the sine sideband). To accomplish this, disconnect the carrier out cable and terminate it into a dummy load. Connect the SB No. 1 output cable to the jack where the carrier output cable was connected. Connect the SB No. 2 output cable to a dummy load. Turn the goniometer power off.

In preparation of a space modulation chart, measured values for the different parameters for various field detector angles are listed in table A-1. An additional counterpoise ground check bracket is installed at an azimuth of 78.75°, providing another field detector calibration position.

The following terms and sequence were used:

A. ρ = field detector angle (used in lieu of goniometer angle).

B. $\theta = \rho + 45$ = azimuth of field detector location.

C. 100 = percent modulation.

$$\frac{1 - \sin\rho}{1 + \sin\rho}$$

(Notice that values for parameters in lines A, B, and C are related by their physical geometry. These values can be determined and entered in the table prior to any electrical measurements.)

D. E = Field Intensity (measured by digital voltmeter).

E_M = Maximum field intensity at $\rho = 90$.

E and E_M were measured from tne detected waveforms jack (J7) on the Wilcox model 585B monitor panel.

E. $E_{100} = 100 \times \dfrac{E}{E_{max}}$

(proportions the scale to 100)

F. $\dfrac{E_{100}}{2.5}$ = scale proportion to 40 for convenient use on the oscilloscope.

To develop column E of table A-1, the following sequence is used:

Place the field detector at the 45° azimuth bracket and record the digital voltmeter reading at J7 on the monitor panel. Continue recording the voltmeter readings for each azimuth bracket location between 45° and 135°. Figure A-1 is a space modulation chart plotted from the data in table A-1.

TABLE A-1. VALUES FOR SPACE MODULATION CHART

A	B	C
Degrees	Degrees	Modulation Percent
0	45.0	100
22.5	67.5	44.6
33.75	78.75	28.57
45.0	90.0	17.16
67.5	112.5	3.96
90.0	135.0	0

D	E	F
Volts	100	100/2.5
0.01	0	0
6.85	44.63	17.85
9.40	61.24	24.5
11.59	75.51	30.2
14.35	93.49	37.4
15.35	100.00	40.0

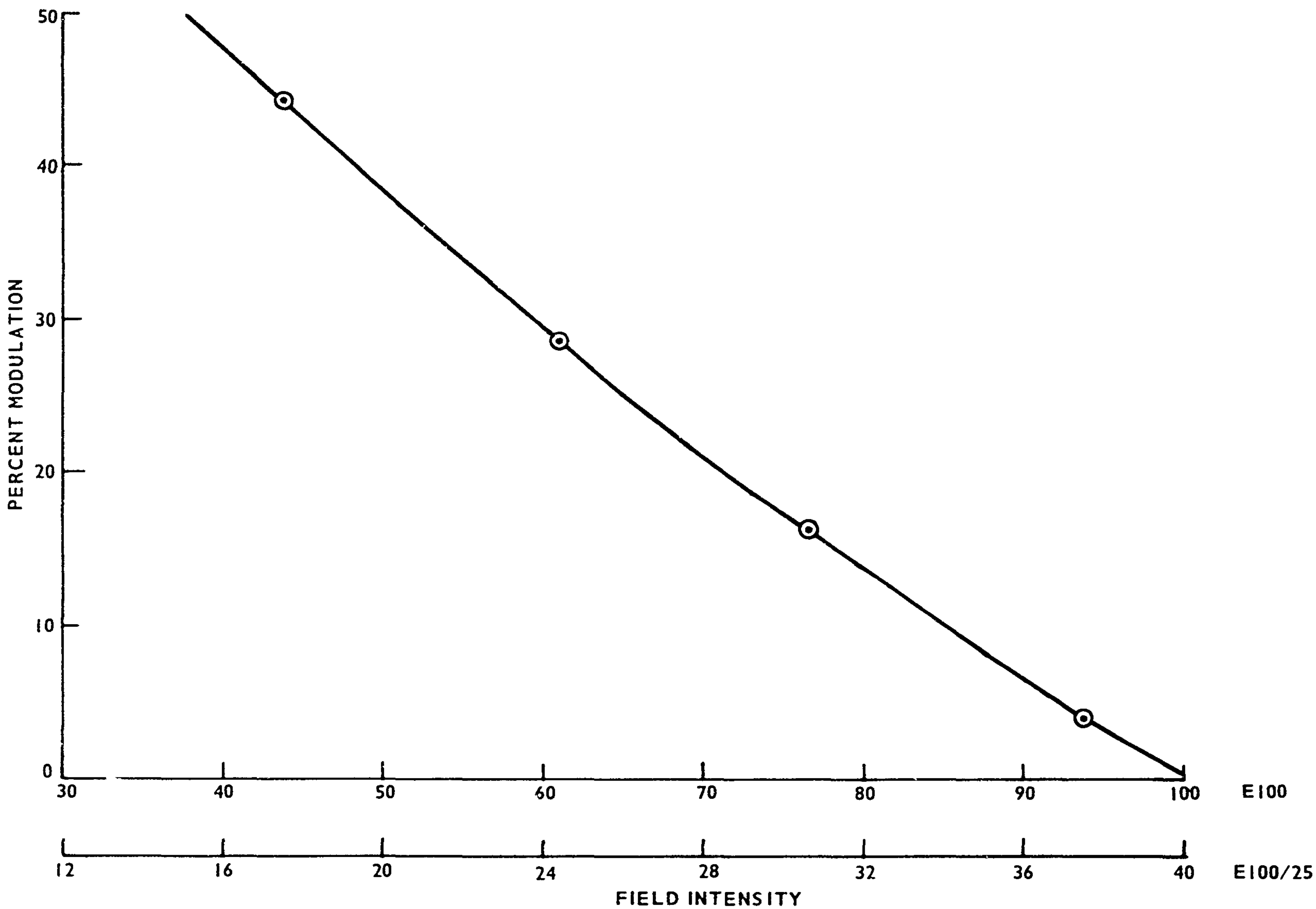


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FIGURE A-1. SPACE MODULATION CHART

APPENDIX B

INVESTIGATION OF WILCOX 585B VOR SYSTEM (PART I)

NAFEC TECHNICAL LETTER REPORT

NA-80-27-LR

INVESTIGATION OF WILCOX
585B VOR SYSTEM
(PART I)

by

WAYNE BELL

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NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
Atlantic City, New Jersey 08405

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This document is disseminated to provide for quick reaction release of technical information to selected users. The contents may not conform to FAA formal publication standards and the technical information is subject to change and/or incorporation into a formal publication at a later date.

Approved by

JOSEPH M. DEL BALZO
Director, National Aviation Facilities Experimental Center
Federal Aviation Administration
Department of Transportation

ABSTRACT

Tests were accomplished on three standard and three modified field detectors with adjustable length elements to investigate reduction of ground check error curve and scalloping at VOR sites with the Wilcox equipment. Orbital and radial flights were accomplished at 116.7 MHz which verified improvement with modified field detectors. A drawing of the field detector element with adjustable sleeve is included to facilitate fabrication. A figure is included to provide guidance for setting detector elements to optimum length at Wilcox VOR facilities operating with a 21-foot diameter counterpoise.

PURPOSE

The purpose of this effort was to test a Wilcox 585B VOR system to determine the magnitude of the ground check error component caused by the field detector/element. Raising the field detector above radio frequency ground and optimizing the length of the detector antenna elements were the only design factors included in this initial test phase.

BACKGROUND

There are several VOR stations in the National Airspace System operating with waivers because the initial adjustment did not conform to the criteria in FAA Handbook 6790.4A. A request by FAA Form 9550-1, AAF-410-078-003 was initiated for NAFEC to investigate ground check error components. Several system elements that can contribute to error include monitor/field detector, antenna, goniometer, transmitting equipment, and counterpoise.

DESCRIPTION OF TEST FACILITY

The Wilcox VOR system operating initially at a frequency of 116.7 MHz was installed in a 21-foot diameter metal drum type shelter. Location of the shelter was at the center of a 400-foot diameter asphalt pad (formerly NAFEC MOPTAR Site). Figure 1 shows the types of field detectors employed in this test phase.

TEST PROCEDURE AND RESULTS

The monitor/field detector was used when making ground checks to determine bearing accuracy of the VOR system. The detector supplies a demodulated signal to the monitor and a comparison was made to a preset signal level. If the detected signal was not within the preset limit, an alarm was initiated.

Three standard Wilcox field detectors were used in the investigation. In each detector tested (figure 2), care was taken to keep coil L1 center-tap balanced with the coil being compressed or expanded to allow capacitor C2A and C2B to be adjusted for maximum signal. Detector balance was measured by the difference between the monitor resolver dial readings with the field detector mounted normally and when the field detector was reversed 180 degrees. Tests were made with a standard detector/element which has 12 7/8-inch elements and a grounded center-tap to coil L1. These tests were repeated with each sample modified with on Ohmite Z144 1.8 microhenry RF-choke added as shown in figure 2.

Providing adjustable elements on the field detector was an additional modification that was accomplished (figure 3). Tests to determine proper element length for 116.7 MHz and a radial distance of 10.5 feet utilized a test setup shown in figure 4. A Yagi antenna was used with monitor #1 and a Hewlett Packard Model 7402 recorder was used to record error for various detector element lengths. Monitor #2 connected to the detector with adjustable elements was used to assure sufficient signal was available when minimum interference was observed on Monitor #1.

Results of these tests accomplished at 116.7 MHz are shown as follows:

Figure 5, the course offset error obtained with various element lengths; figure 6, the bearing error obtained with various element lengths; figure 7, the ground check error with modifications and optimum element length; and table 1, tabulates the improvement with modifications and adjustments compared to standard detector.

Orbital and radial flights were accomplished at 1,500 feet mean sea level (MSL) with guidance provided by extended area instrumentation radar (EAIR). Orbital flights at 5 and 20 nmi demonstrated that the VOR system was within tolerance. The results of the radial flights shown in figure 8 indicate the reduction of scalloping using the modified detector with proper length elements. Optimum element length could be decreased as indicated by the curves to reduce course and bearing error, but the loss of signal resulting from shortening the elements at this frequency restricted further reduction in element length.

Ground measurements were accomplished at 109 MHz and 112.24 MHz to provide information on the optimum detector element length for various frequencies. Results of the course and bearing errors for 109 MHz are shown in figures 9 and 10 respectively, and similarly figures 11 and 12 are the results for 112.25 MHz. With the optimum element length established at 109 MHz and 116.7 MHz, an optimum length was predetermined for 112.25 MHz assuming that optimum element length varied linearly with frequency as shown in figure 13. However, the measured value at 112.25 MHz for the optimum element length did not agree with the assumed value. Consequently, the proper element lengths for other frequencies should be determined by the solid line in figure 13 at field sites with a Wilcox 585 VOR system and a 21-foot counterpoise.

CONCLUSIONS

Based on the test results, it can be concluded:

1. System improvement was obtained with the modification in adding a RF choke and keeping the L-C circuit in the detector above RF ground.

2. Additional improvement was obtained by adjusting field detector elements to the proper length corresponding to frequency.

RECOMMENDATIONS

1. The modifications of the additional RF choke and the use of adjustable elements on the field detectors be employed at field sites with a Wilcox 585 VOR system.

2. Measurements be accomplished at sites with a Wilcox 585 VOR system employing counterpoise of 32-foot and 52-foot diameter to determine system performance with appropriate detector element lengths.

This project was accomplished under NPD 04-309, Subprogram 041-305-830. For further information, contact Wayne Bell or Edward M. Sawtelle, NAFEC Program Manager, ANA-100B.1, telephone FTS 8-346-3911, commercial (609) 641-8200, extension 3911. Results of this report will be included in a final report covering additional system elements on the Wilcox VOR system.

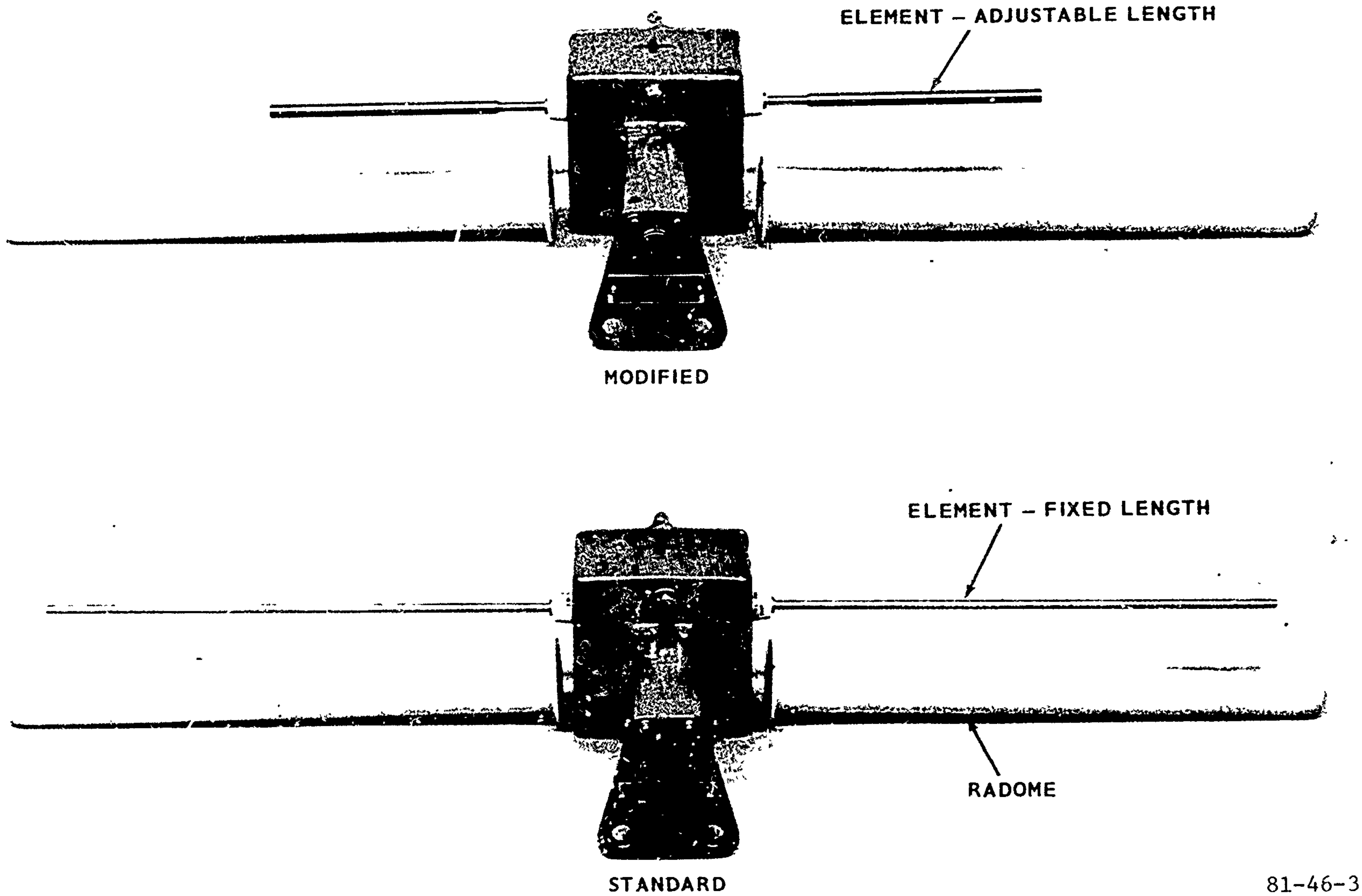
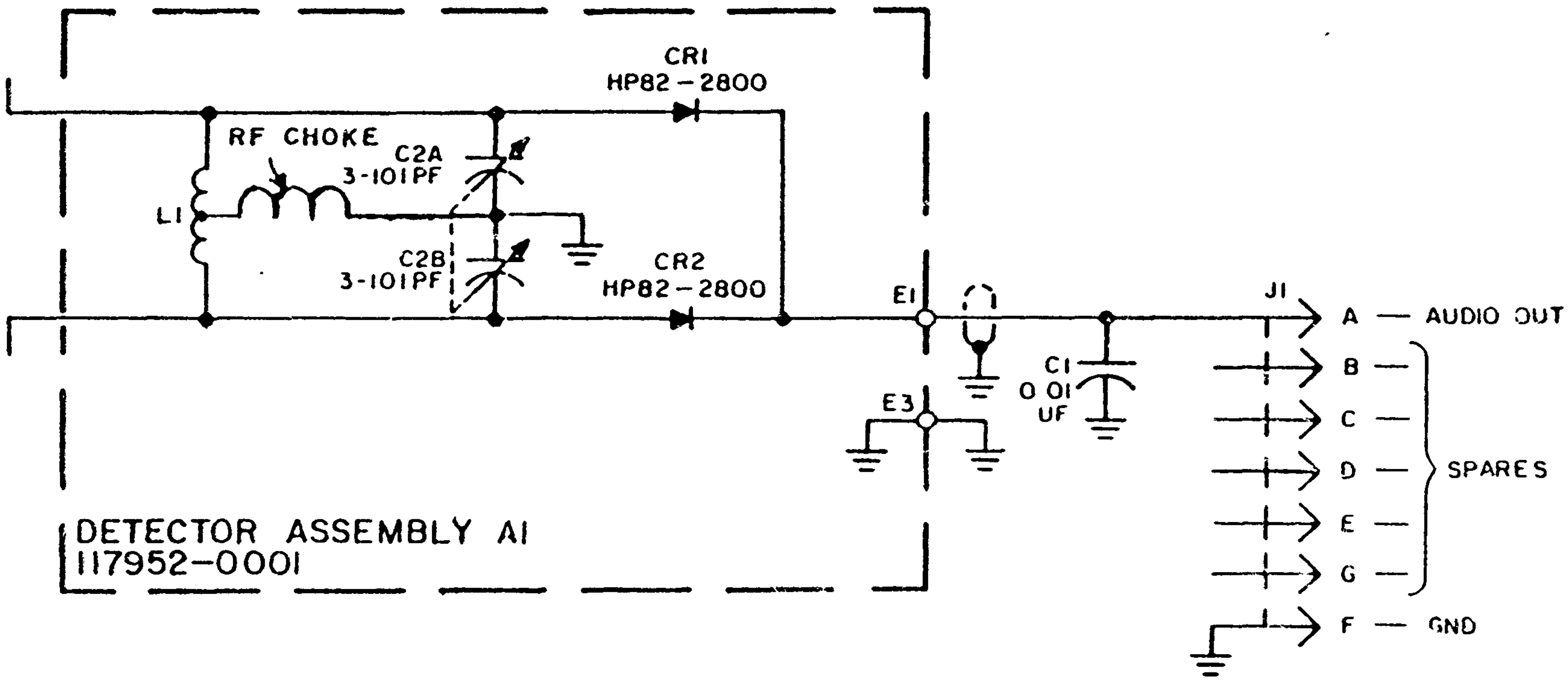
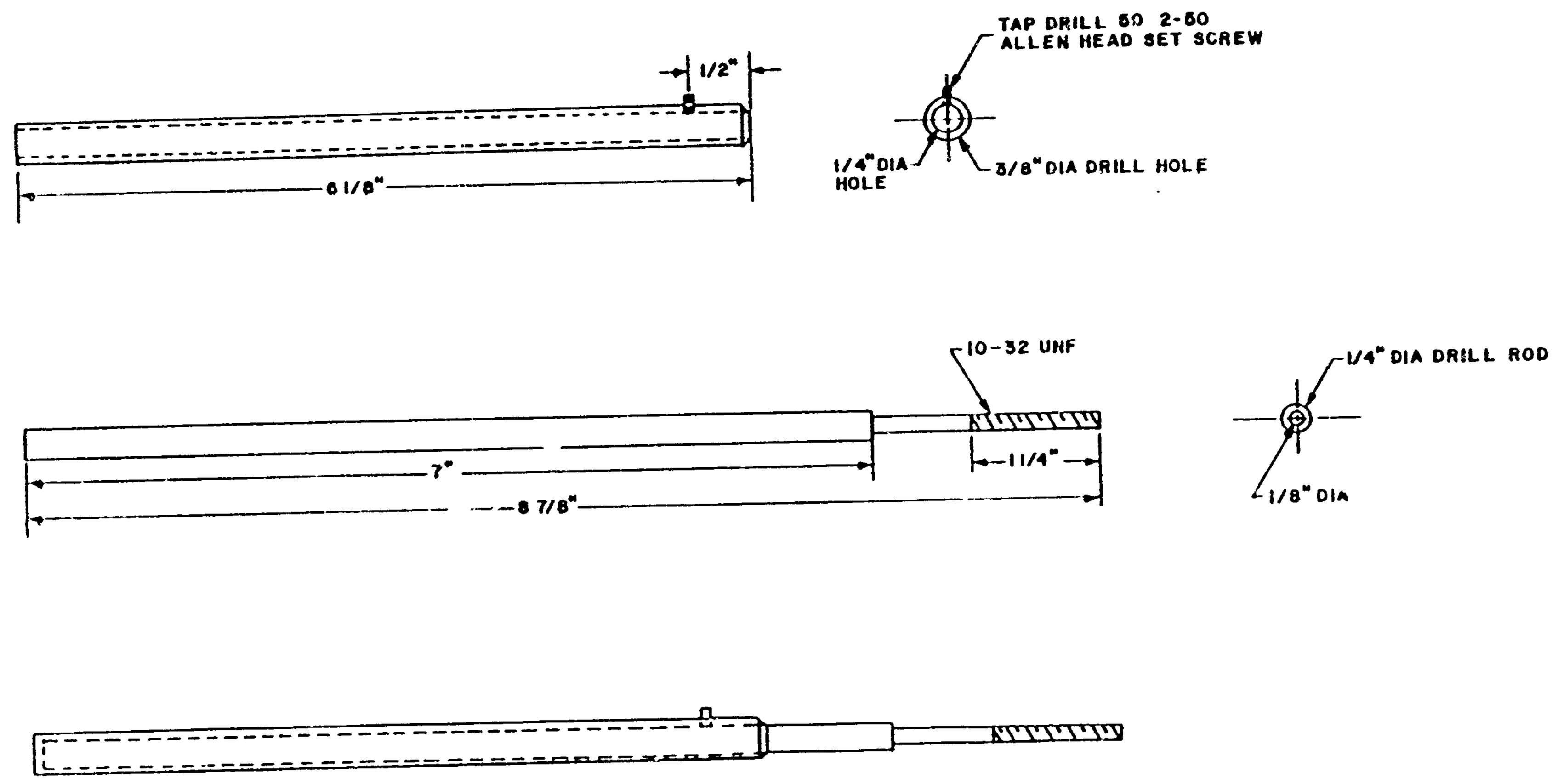


FIGURE 1 STANDARD AND MODIFIED WILCOX FIELD DETECTOR



NOTE: RF CHOKE WAS ADDED TO ORIGINAL DETECTOR ASSEMBLY

FIGURE 2. MODIFIED WILCOX FIELD DETECTOR SCHEMATIC DIAGRAM



NOTE: REDUCE DETECTOR ELEMENT AND SLEEVE FOR HIGH END OF FREQUENCY BAND

FIGURE 3. FIELD DETECTOR ELEMENT WITH ADJUSTABLE SLEEVE

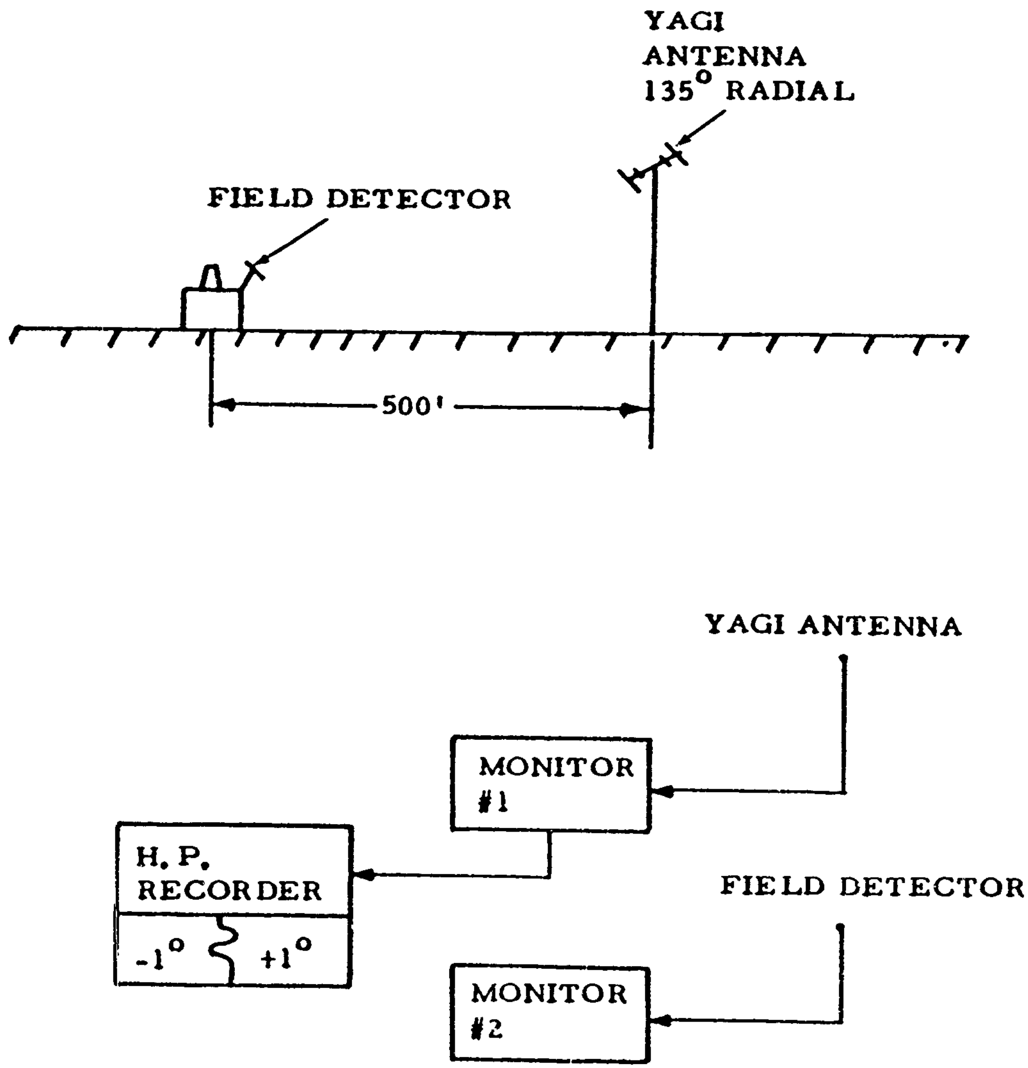


FIGURE 4. TEST SETUP USED TO DETERMINE PROPER FIELD DETECTOR ELEMENT LENGTH

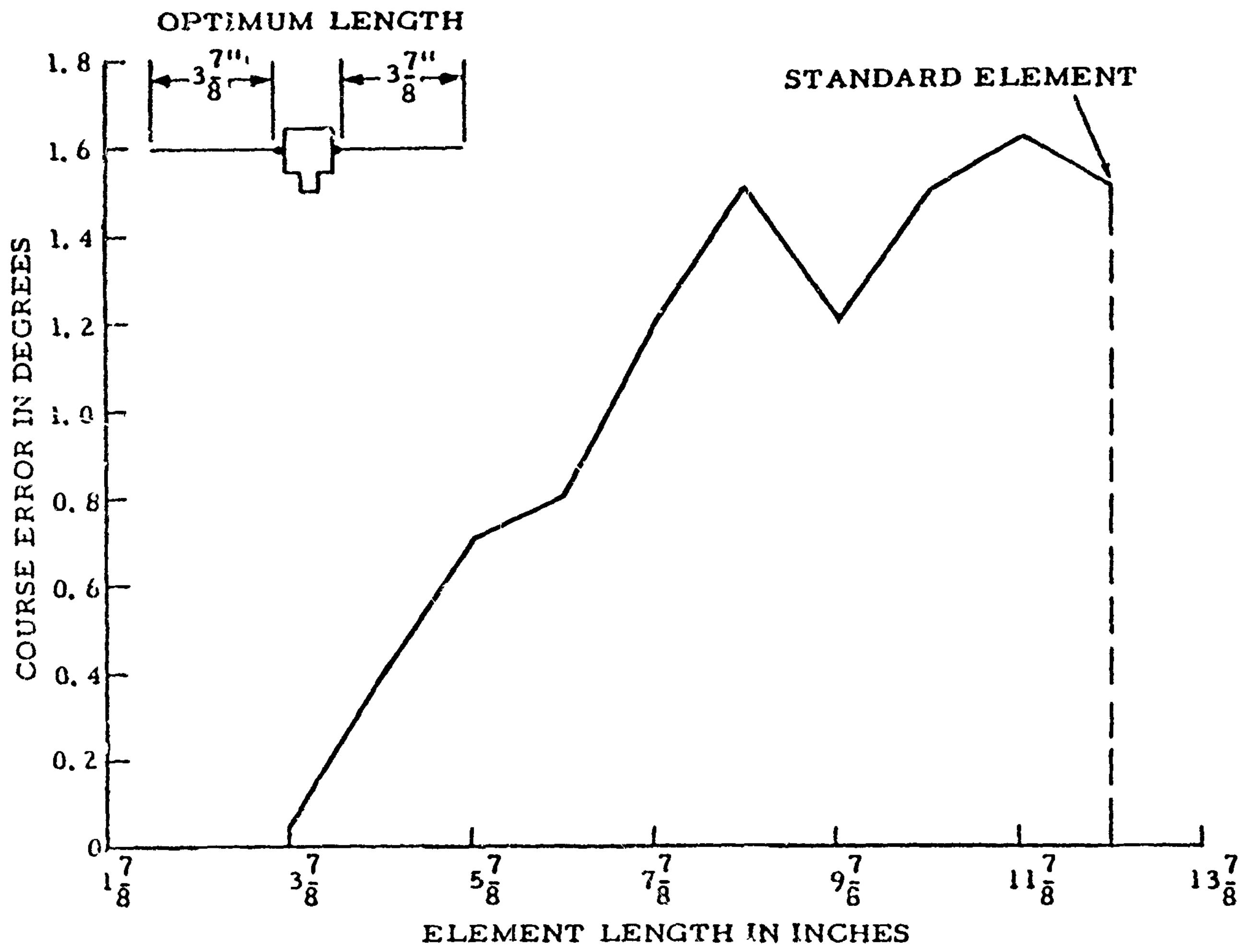


FIGURE 5. COURSE OFFSET ERROR, FREQUENCY 116.7 MHz

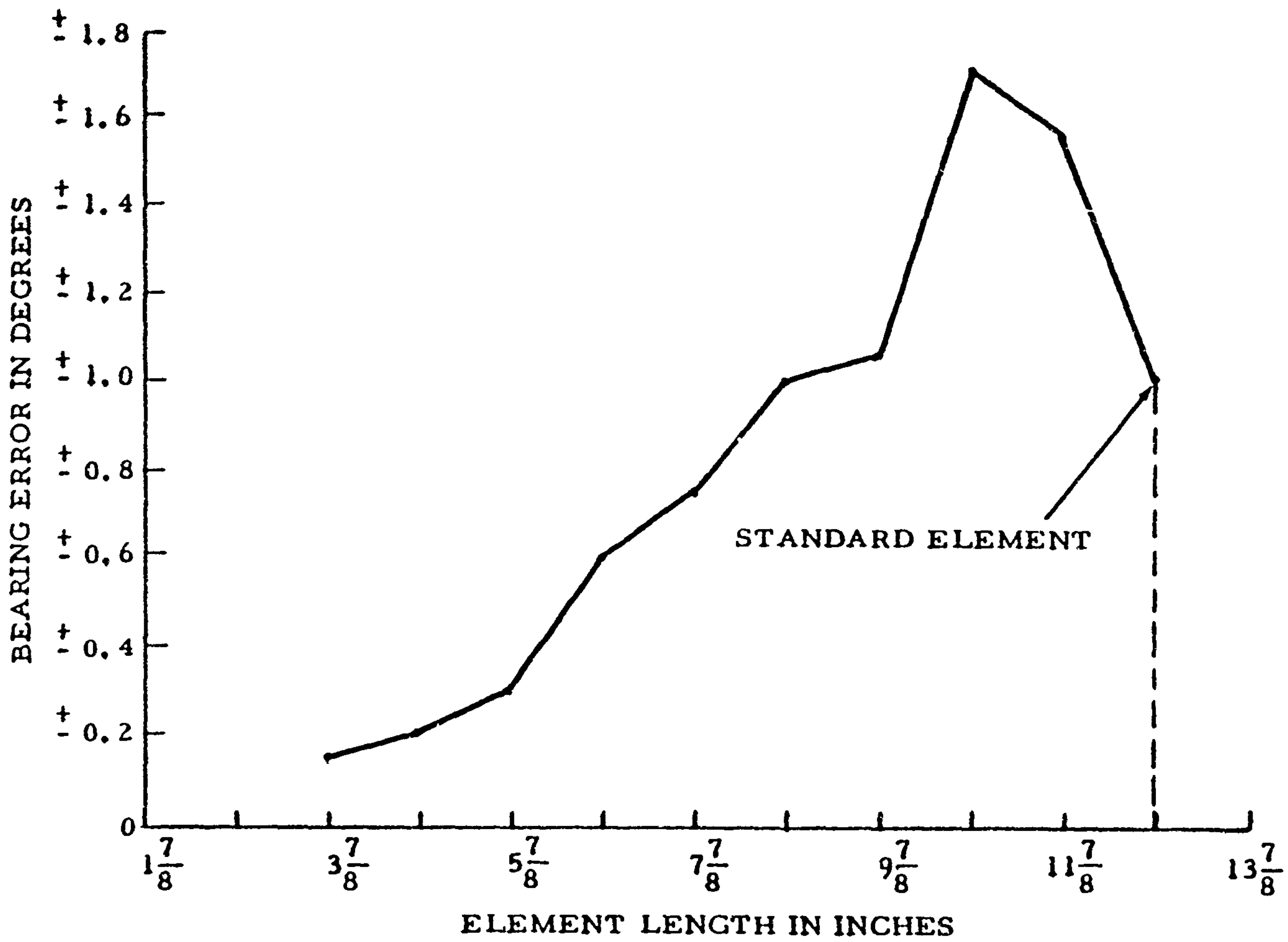


FIGURE 6. MAXIMUM BEARING ERROR, FREQUENCY 116.7 MHz

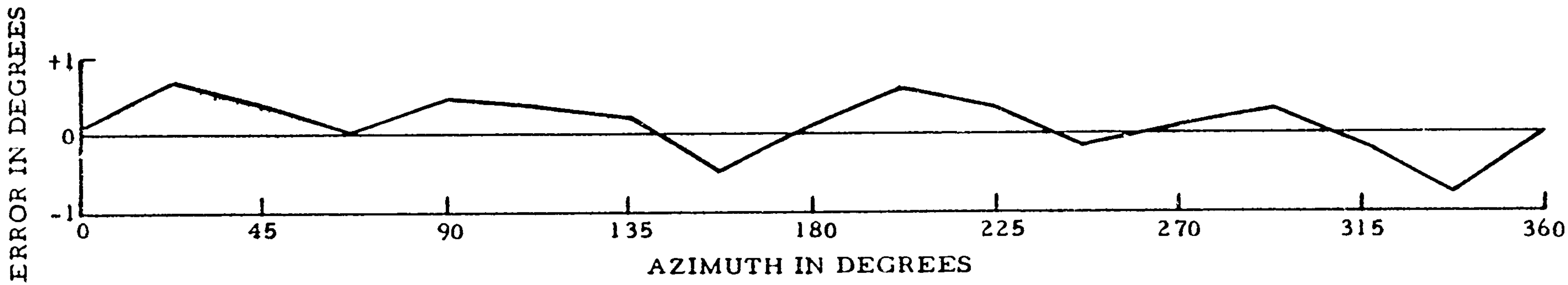


FIGURE 7. GROUND CHECK ERROR CURVE, FREQUENCY 116.7 MHz

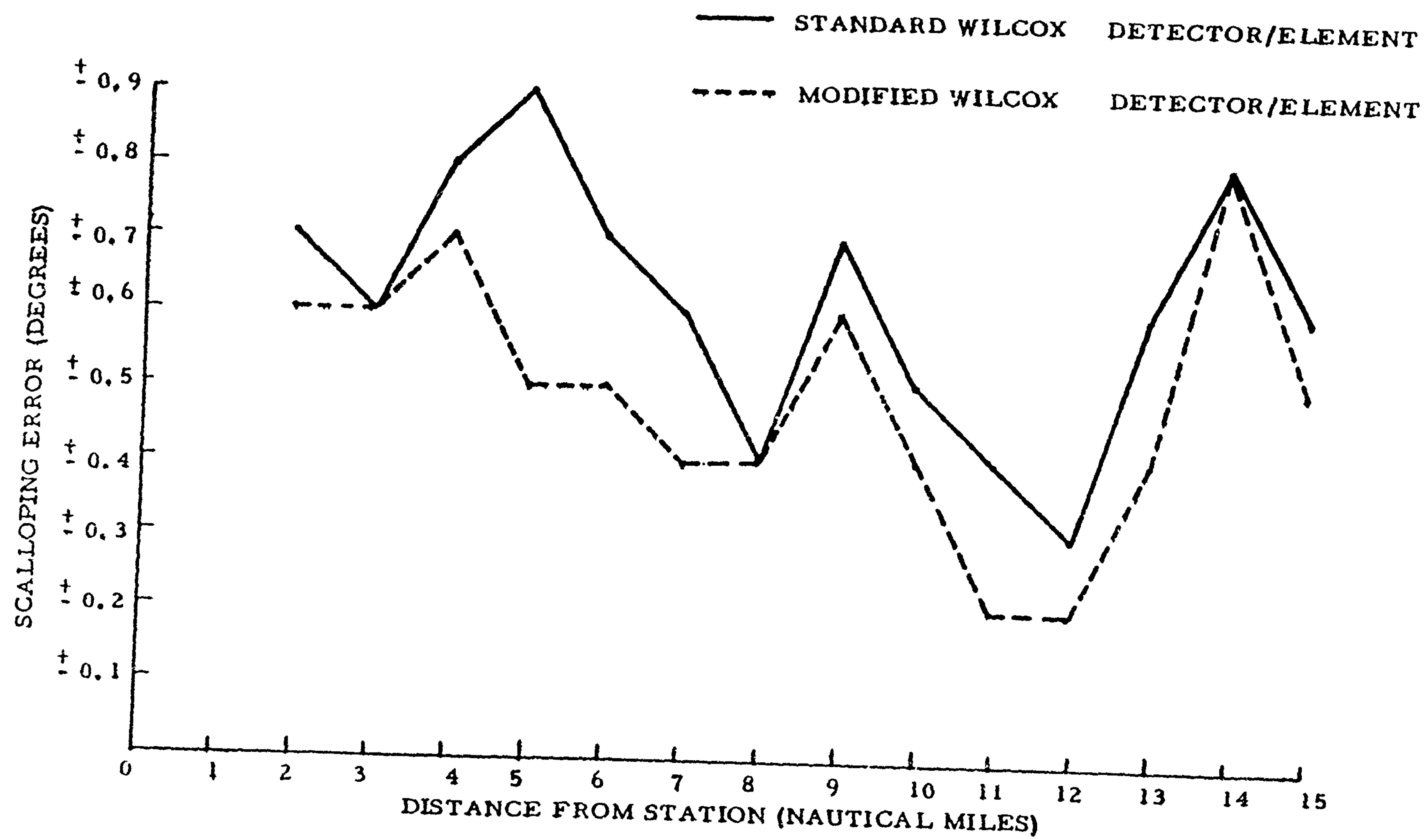


FIGURE 8. INDICATED SCALLOPING, 135° RADIAL INBOUND, MODIFIED VERSUS STANDARD DETECTOR/ELEMENT

FIELD DETECTOR SAMPLE	CONDITION	DETECTOR BALANCE ERROR (DEGREES)	REDUCTION IN GROUND CHECK ERROR (DEGREES)
#1	STANDARD DETECTOR	± .6	
	RF CHOKE	± .15	.2
	MODIFIED DETECTOR/ELEMENT	± .1	.1
#2	STANDARD DETECTOR	± .4	
	RF CHOKE	± .15	.3
	MODIFIED DETECTOR/ELEMENT	± .15	0
#3	STANDARD DETECTOR	± .2	
	RF CHOKE	± .15	.1
	MODIFIED DETECTOR/ELEMENT	± .15	.1

TABLE 1. DETECTOR BALANCE READINGS AND OVERALL GROUND CHECK IMPROVEMENT.

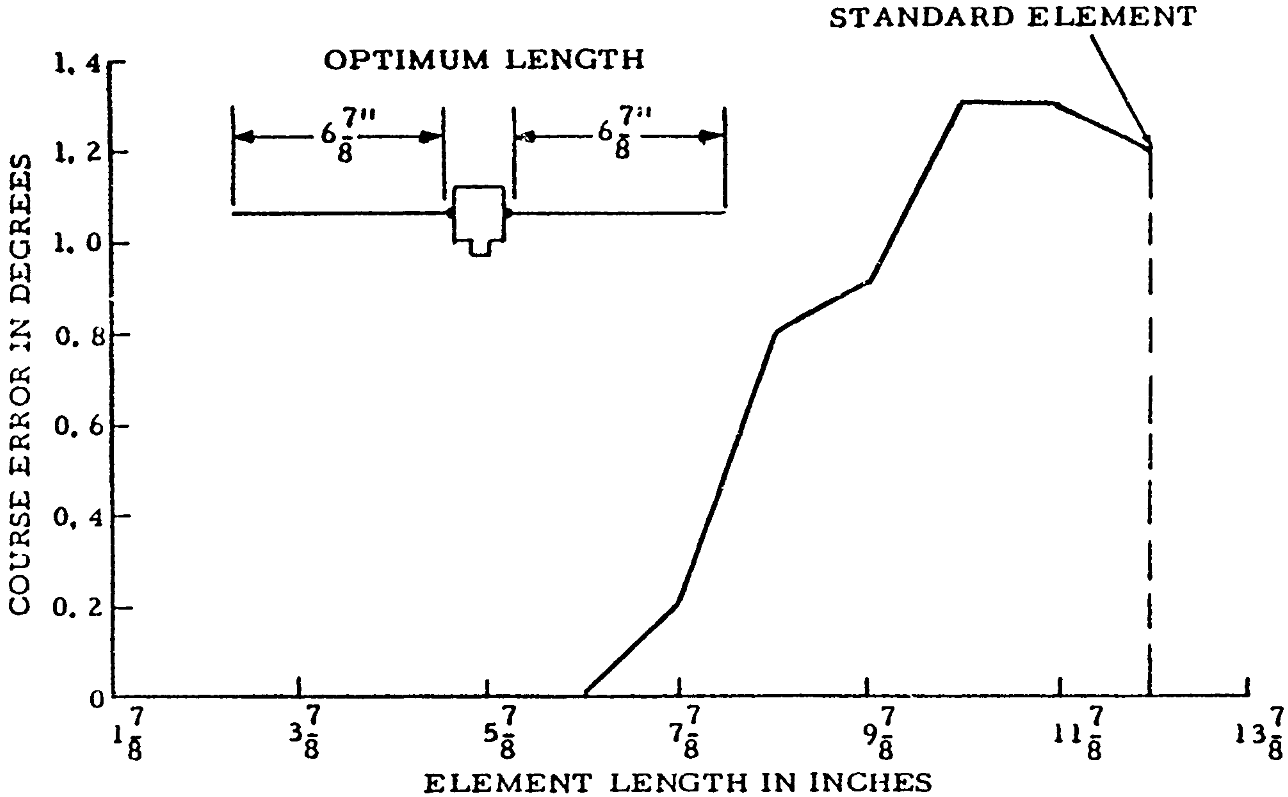


FIGURE 9. COURSE OFFSET ERROR, FREQUENCY 109.0 MHz

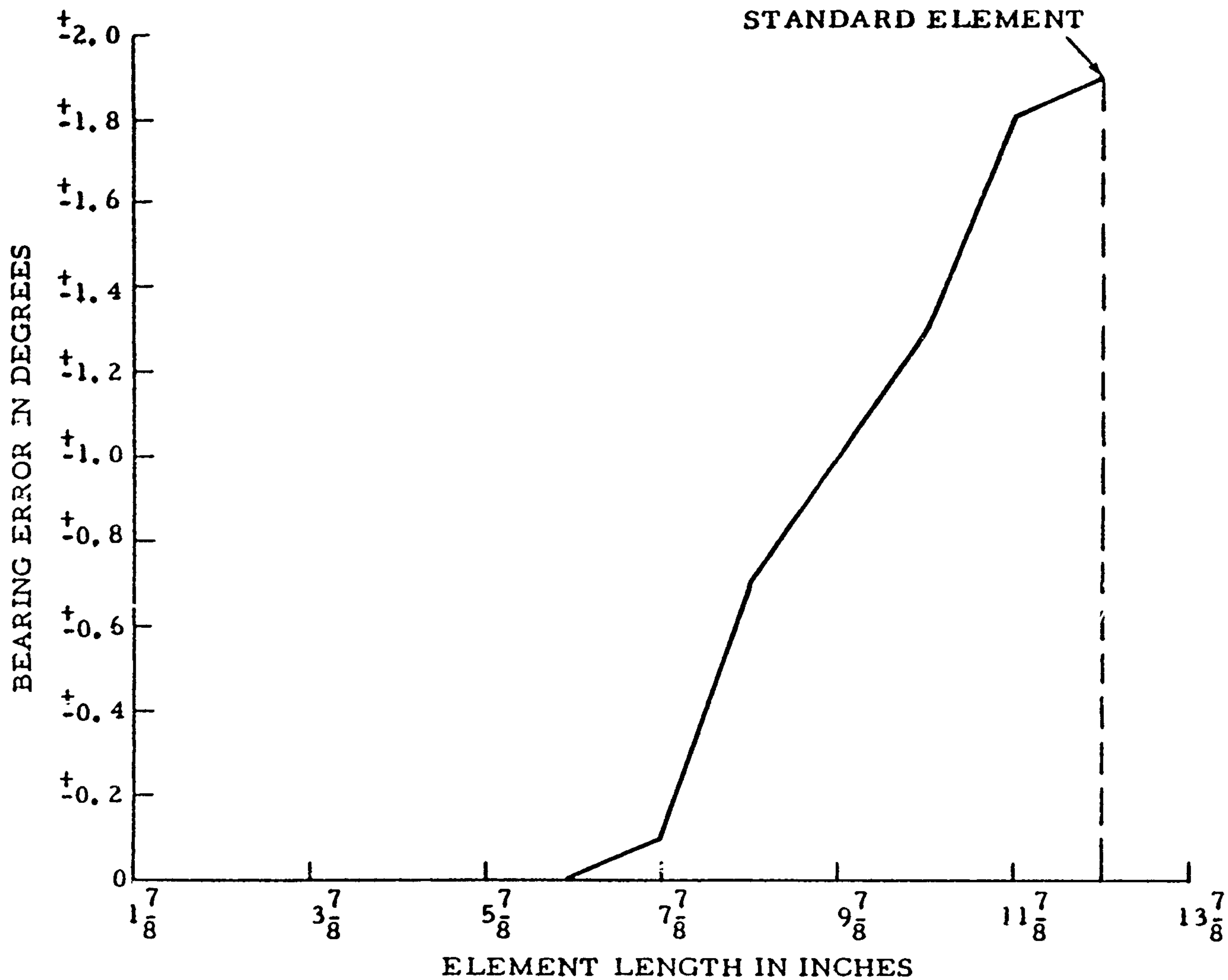


FIGURE 10. MAXIMUM BEARING ERROR, FREQUENCY 109.0 MHz

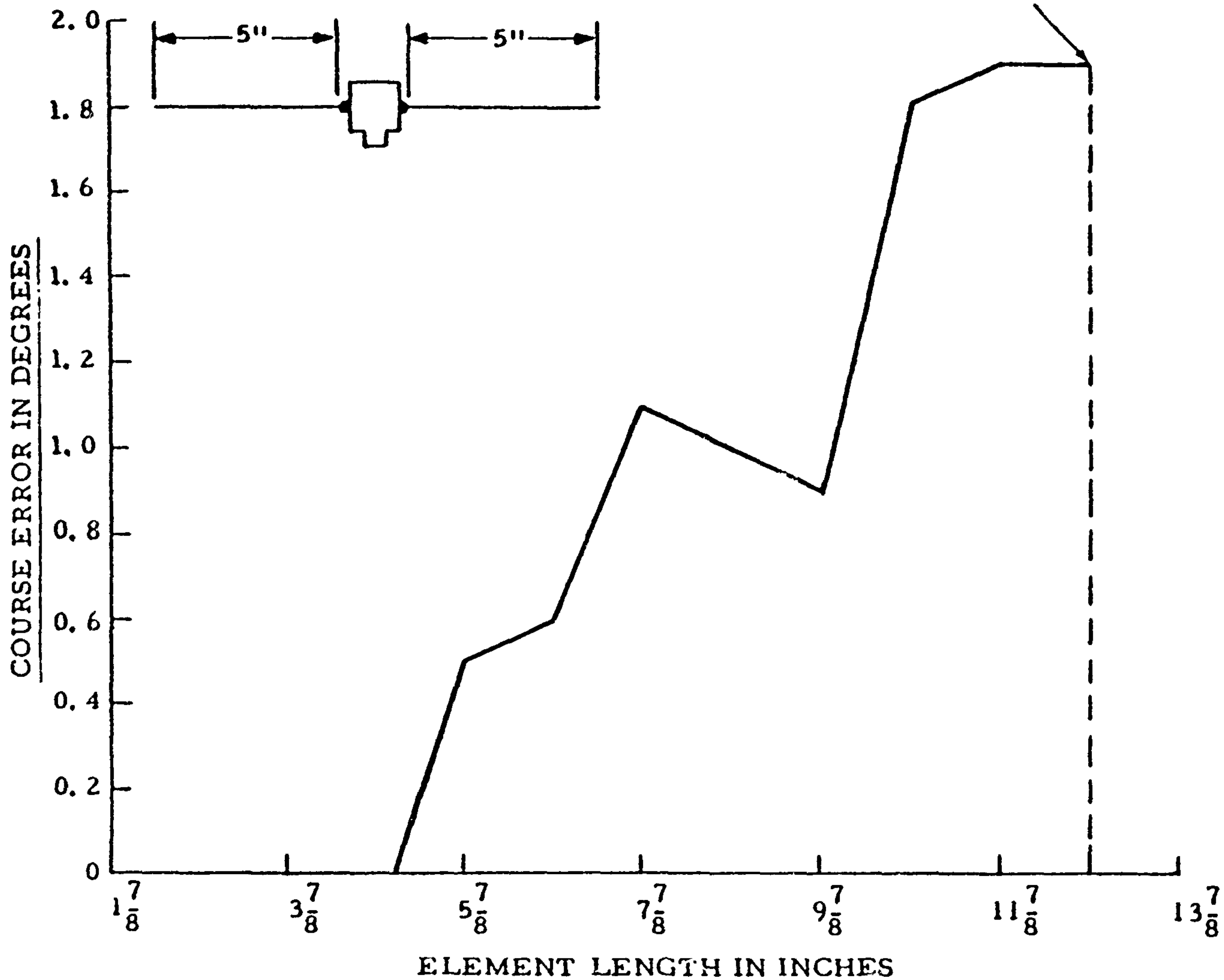


FIGURE 11. COURSE OFFSET ERROR, FREQUENCY 112.25 MHz

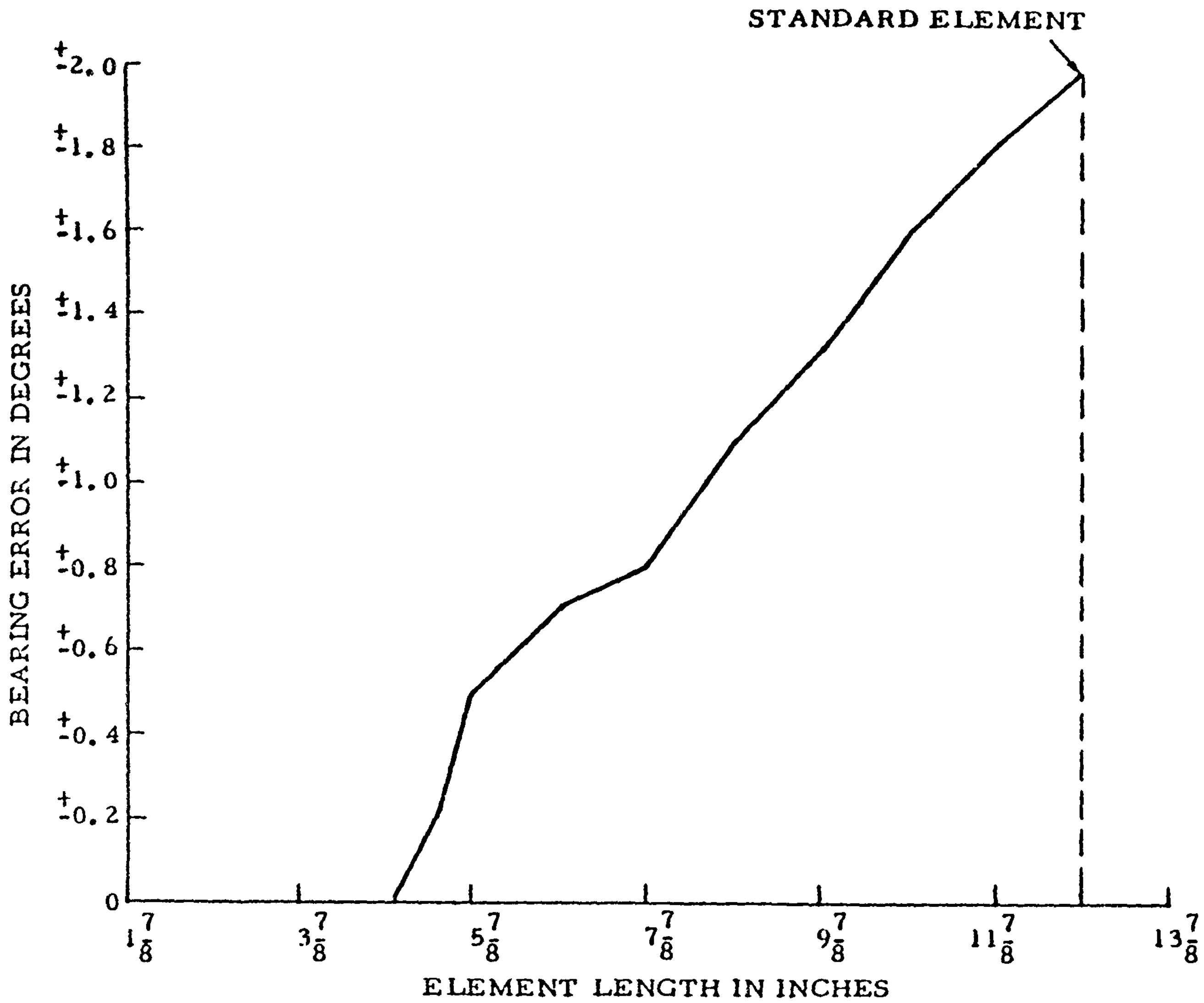


FIGURE 12. MAXIMUM BEARING ERROR, FREQUENCY 112.25 MHz

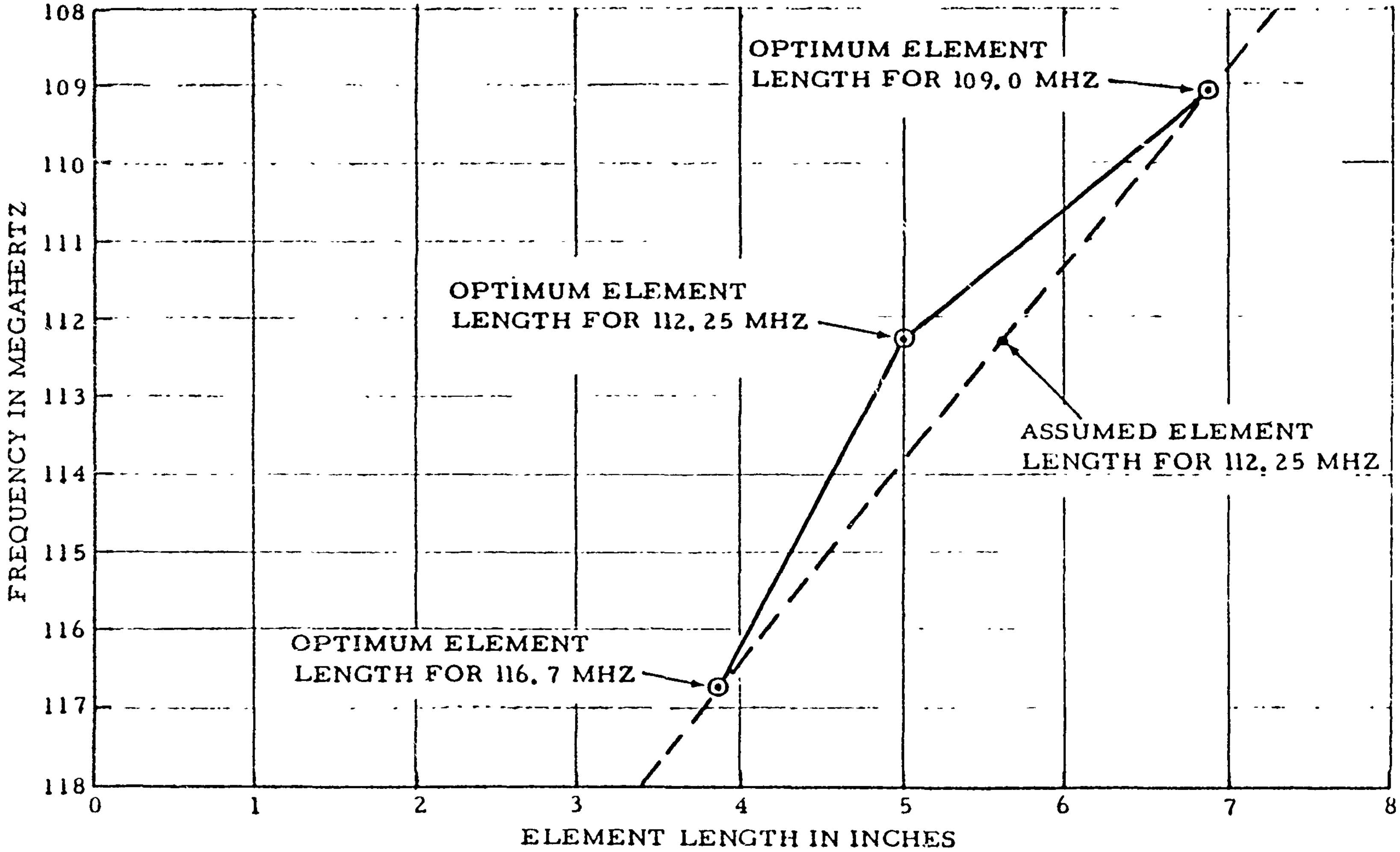


FIGURE 13. WILCOX DETECTOR ELEMENT ADJUSTMENTS